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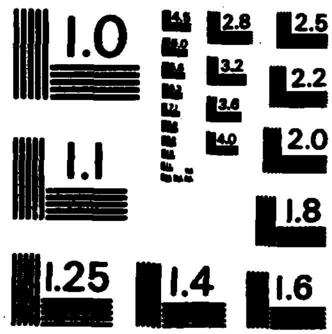

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USE OF THE GPIB
FOR
DATA COLLECTION AND DISPLAY

by

Thomas Taylor

June 1985

Thesis Advisor: John P. Powers

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The objective of this study is to examine the uses of a General Purpose Interface Bus (GPIB) to link a microcomputer controller to computer-controllable test equipment. The Hewlett-Packard HP-85 microcomputer is examined as the systems controller. The test equipment is configured to conduct basic electronic laboratories and the results are compared with current manually-controlled test equipment.

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Use of the GPIB for Data Collection and Display

by

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Lieutenant, United States Navy
B.S., University of Utah, 1977

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ABSTRACT

The objective of this ~~study~~ thesis is to examine the uses of a General Purpose Interface bus (GPIB) to link a microcomputer controller to computer-controllable test equipment. The Hewlett-Packard HP-85 microcomputer is examined as the system controller. The test equipment is configured to conduct basic electronic laboratories and the results are compared with current manually-controlled test equipment. Test equipments evaluated include: The Wavetek Model 270 programmable function generator, Tektronix DC5009 programmable counter/timer, Tektronix DM5010 programmable digital multimeter, Tektronix PS5010 programmable power supply, Hewlett-Packard 1615A programmable logic analyzer, and the Photodyne Model 488XII GPIB interface with digital power meter. These equipments and others are evaluated singlely and in combination. Various methods for displaying and plotting acquired data are discussed and evaluated.

Keywords: Computer programs,

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I. INTRODUCTION

Spurred by the low cost and availability of microcomputers and other similar products of the integrated circuit revolution, new uses of microcomputers and other programmable equipments are becoming widespread. The use of microcomputers to control data acquisition, and, once the data has been acquired, to optimally display results is much faster and often more accurate than manual methods. Basic electronics laboratories for courses such as EC-2211, EC-2212 and EC-2215 taught at the Naval Postgraduate School, and basic digital courses such as EC-2811 and EC-2812 currently use non-programmable test equipment. The use of a microcomputer controller and programmable test equipment could provide the following advantages over the current manual methods:

(1) More consistent results in repeated measurements, since a computer-controlled system is not subject to operator fatigue.

(2) Greater throughput because computer-controlled systems are generally faster than manual methods.

(3) More thorough testing because system speed allows more parameters to be measured in a shorter time.

(4) Results expressed in scientific or engineering units, since many system controllers are capable of on-line data manipulation.

(5) Greater accuracy because system errors can be measured automatically by comparison to theoretical or pretabulated values, stored and accounted for in the results.

(6) Adaptive data acquisition where a system can be programmed to branch to other measurements to help pinpoint problems when it measures an abnormal condition.

(7) Capability to store measurement results in computer memory, on disk or tape, or on a hard copy.

(8) Better data display, since microcomputer-generated graphs and plots have obvious advantages in time and accuracy over those done by hand.

(9) Immediate feedback to students since data plots are readily available for interpretation.

The objective of this study was to show how the use of a microcomputer and programmable test equipment could replace the current procedure for conducting basic electronic laboratories. Methods for data collection and display were examined and compared to manual methods.

To meet the objectives of this study various programmable test equipments were evaluated . Programs for the HP-85 computer were written to aid in the evaluation. Chapter II discusses the General Purpose Interface Bus and gives some background on its adoption as IEEE Standard 488-1978. Chapter III is an introduction to the equipment used in this study including a summary of each equipment's capabilities. Chapter IV discusses the use of programmable test equipment for data collection. The frequency response of a simple circuit is evaluated as a demonstration. Chapter V discusses the display of data acquired from programmable test equipment including computer-generated plots examples of which are shown. Appendix A is an ASCII and IEEE 488 code chart and Appendix B is a collection of the programs developed to demonstrate and evaluate the programmable test equipment.

II. GENERAL PURPOSE INTERFACE BUS

There are many applications where the measurement power of interactive instruments can be further enhanced by coupling them to a desktop computer or minicomputer. Operating in a remote mode can provide more exact, error-corrected results as compared with conventional manual operation techniques.

Presently, three major factors have combined to reduce significantly the engineering development costs of configuring measurement systems:

(1) Distributed computing through the growing number of instruments with internal microprocessors,

(2) The broad choice of computers ranging from inexpensive, easy-to-program desktop computers to more sophisticated computer systems capable of managing multi-station instrument clusters and complex data bases, and

(3) The availability of standard interface equipment such as the GPIB which allows the easy interface of different equipments from different manufacturers.

In 1972, the U.S. Advisory Committee, composed of diverse interests representing both users and manufacturers established initial goals and then adopted an interface concept. The Hewlett-Packard Corporation had for some time been a leader in measurement technology research, and the HP Interface Bus was adopted by the committee as an appropriate starting point. A draft document was subsequently written and evaluated by members of the committee, and then

submitted as the U.S. proposal to the International Electro-technical Commission (IEC) in the autumn of 1972. Since then, the interface has undergone a number of minor changes to accommodate various needs at the international level.

In September 1974, the parent technical committee, IEC TC76, approved the main interface draft document for a formal ballot among the member nations of the IEC. Balloting took place in 1976, and IEC recommendation 625-1 was adopted. The IEC recommendation, using a different connector, is totally compatible with the current HP-IB.

Using the HP-IB as a model the IEEE Standards Board approved IEEE Standard 488-1975 "Digital Interface for Programable Instrumentation (GPIB)", first published in 1975 and again published in 1978 with minor editorial changes as IEEE Standard 488-1978. In January 1976, the American National Standards Institute adopted the IEEE standard and published it as ANSI Standard MC 1.1.

The standardized interface concept is now well accepted. More then 2000 products that are compatible with the IEEE Standard are today available from more then 250 manufacturers over 14 countries.

The GPIB has a party line structure where all devices on the bus are connected in parallel as shown in figure 2.1. The 16 signal lines, shown in figure 2.2, within the passive interconnecting GPIB cable are grouped into three clusters according to their functions as follows:

(1) Data Bus (8 signal lines)
(2) Data Byte Transfer Control Bus (3 signal lines)
(3) General Interface Management Bus (5 signal lines)

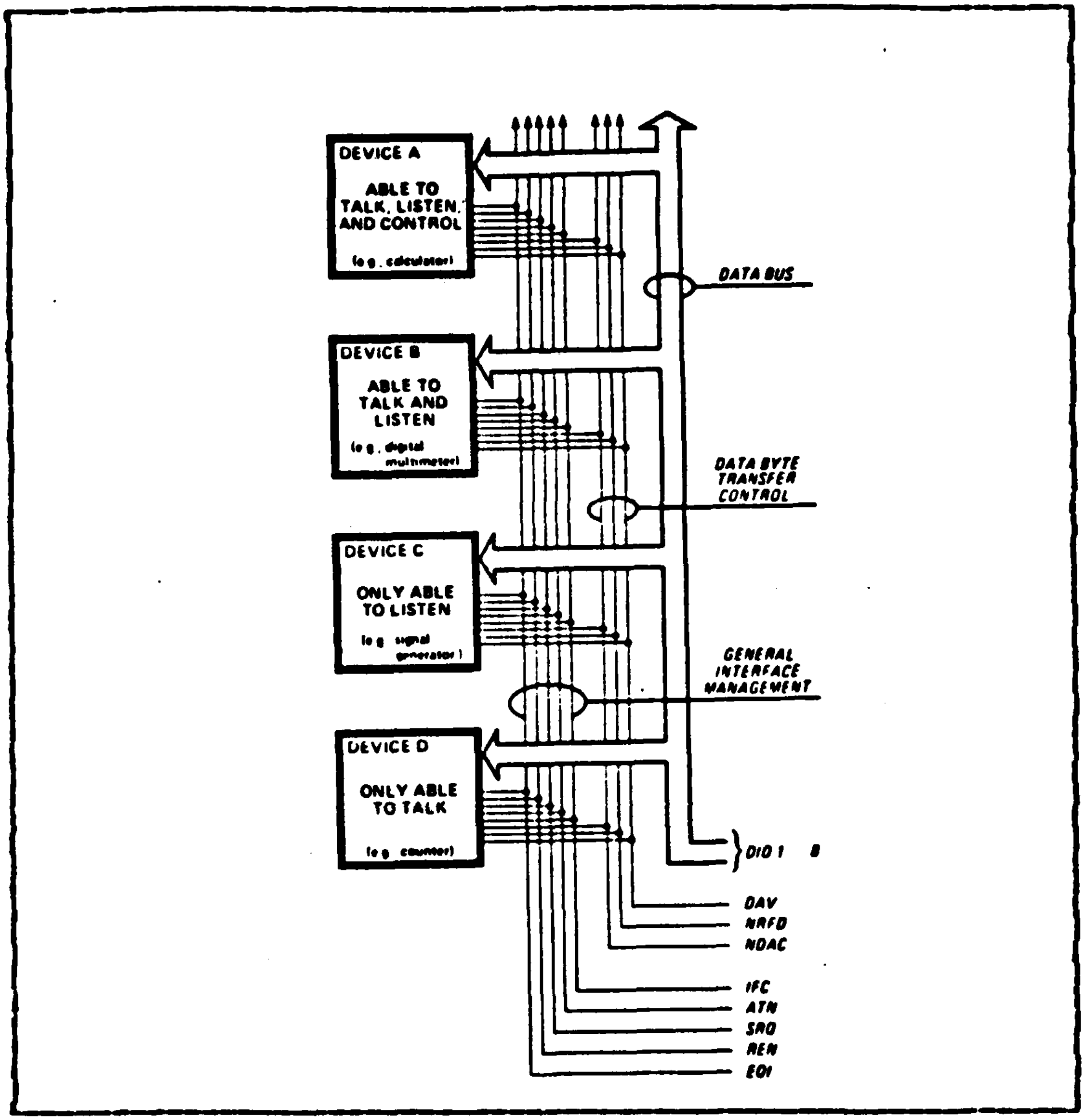

Figure 2.1 GPIB Bus Structure. (from Ref. 7).

The Data Input-Output (DIO) Bus consists of eight signal lines that carry data in a bit parallel, byte serial format across the interface. These signal lines carry addresses, program data, measurement data, universal commands and status bytes to and from devices interconnected in a system. Identification of the type of data present on the DIO signal

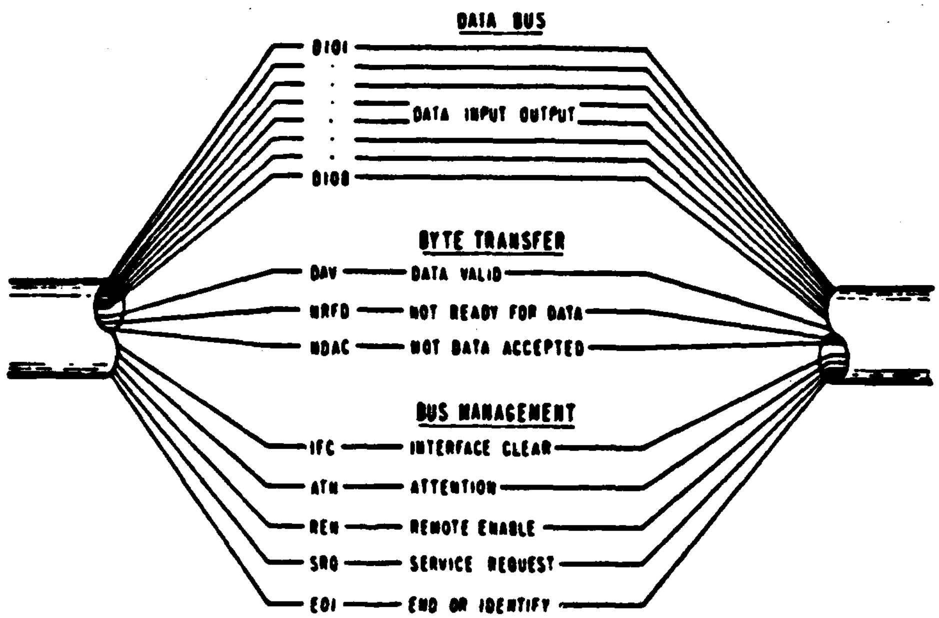

Figure 2.2 GPIB Signal Structure. (from Ref. 7).

lines is indicated by the ATN (attention) signal. When the ATN signal is true (asserted), either address or universal commands are present on the data bus and all connected devices are required to monitor the DIO lines. When the ATN message is false, device dependent data (e.g., programming data) is carried between devices previously addressed to talk and listen.

Transfer of each byte on the Data Bus is accomplished via a set of three signal lines: DAV (data valid), NRFD (not ready for data), and NDAC (not data accepted). These signals operate in an interlocked handshake mode. Two signal lines, NRFD and NDAC, are each connected in a logical AND (wired OR) to all devices connected to the interface.

The DAV signal is sent by the talker and received by potential listeners whereas the NRFD and NDAC signals are sent by potential listeners and received by the talker.

The General Interface Management Lines manage the bus to effect an orderly flow of messages. The IFC (interface clear) message places the interface system in a known quiescent state. SRQ (service request) is used by a device to indicate the need for attention or service and to request an interruption of the current sequence of events. REN (remote enable) is used to select between two alternate sources of device program data. EOI (end or identify) is used to indicate the end of a multiple byte transfer sequence or, in conjunction with ATN, to execute a polling sequence.

Data byte transfer on the DIO signal lines is accomplished using an interlocked handshake sequence on three signal lines; data valid (DAV), not ready for data (NRFD) and not data accepted (NDAC). The talker uses DAV to signal the presence of a valid byte of data on DIO1-DIO8. Each listener indicates its acceptance of the data by asserting RFD message false and DAC message true. The talker then asserts the DAV message false and the listener, when it is able to receive a new data byte, asserts RFD true and DAC false. Thus the handshake sequence is complete. When two or more devices are "listening" each device participates in the same handshake cycle. Data is transfered asynchronously at the rate of the slowest listener.

A more complete discussion of the GPIB can be found in the IEEE Standard [Ref. 7].

III. EQUIPMENT

In this chapter various GPIB compatible equipment will be discussed. That equipment which seem most likely candidates for basic electronic laboratory use are discussed first and in greater detail. Equipment whose use is less readily apparent and some equipment where less research was conducted are discussed last.

A. HP-85 COMPUTER AND HP-IB

The Hewlett-Packard Interface Bus (HP-IB), is Hewlett-Packard's implementation of the IEEE-488-1978 interface standard (GPIB). As discussed in Ref. 1, the purpose of the HP-IB is to provide mechanical, electrical, timing, and data compatibilities between all devices adhering to the standard. Interfacing other devices to computers has been greatly simplified by the HP-IB. In general the use of the HP-IB allows the operator to concentrate on what is to be communicated and give little thought to compatibility and handshaking. The HP-IB uses standard ASCII and easily understood control signals.

If one uses the HP-IB option accessory, the Hewlett-Packard Model 85 microcomputer has the necessary capabilities to allow it to function as system controller. Using the HP-IB, the HP-85 can take control of programmable test equipment, direct their operation, and store test data returned from the equipment. The computer can store data on magnetic disk or tape, display the data using built-in graphics capabilities or a remote plotter, or print a hard copy of the data.

Three primary commands that the HP-85 uses to control programmable test equipment are the "OUTPUT", "ENTER" and "TRANSFER" commands. The "OUTPUT" command is used to send data from the computer to the test equipment. The statement must contain the destination device address and a list of items to be output (e.g. the command OUTPUT 720; X, outputs the variable X to device 720). The "ENTER" command is used to send data from a designated equipment to the computer. The statement must contain the source device address and a list of items to be entered (e.g. the command ENTER 720; X, enters data to variable X from device 720). The "TRANSFER" command is used to move data to and from a established buffer area. This command is used to move data from one device to another when neither device is the bus controller (e.g. the command TRANSFER 706 TO Z$ COUNT 100, will transfer 100 bytes of data from device 706 to the buffer space designated as Z$. The command TRANSFER Z$ TO 710 FHS, will transfer the data in buffer space Z$ to device 710 using fast-handshake).

When a device encounters a situation which requires the controller's attention or action, it signals the controller with a service request (SRQ). A service request may be generated whenever an event such as an error or change of status occurs. A service request is handled by the controller as an interrupt and may be processed or ignored. If the controller is programmed to process the SRQ Interrupt it must first determine who sent the interrupt, and then why the SRQ was generated. The controller can determine who sent the service request by performing a parallel poll. This is like a discussion leader asking those persons with problems to raise their hands. Once the controller determines which device generated the SRQ, it can determine the specific problem by performing a serial poll. This involves

querying a device as to its status. The information returned by each device is dependant upon the nature of the device and can be found in the instruction manual for that specific equipment (e.g. error code 98 indicates an execution error for the Tektronix PS 5010 but could indicate a different type of error for some other device). A complete discussion on handling service requests can be found in Ref. 1.

B. WAVETEK FUNCTION GENERATOR

This section discusses the Wavetek Model 270 Programmable Function Generator and how to control it using the HP-85 Microcomputer.

As described in Ref. 2, the Wavetek Model 270, 12 MHz Programmable Function Generator, is a 0.01 Hz to 12 MHz multifunction generator that can operate in continuous, trigger, gated or burst modes, at generator levels to 20 volts peak-to-peak. The generator produces sine, triangle, and square waves, with from +5 to -5 volts of DC offset. The function generator settings can be made from the front panel or, with the General Purpose Instrument bus, from a microcomputer controlling the experiment. Numbers can be input in free format, (i.e. fixed point, floating point, or exponential notation). Parameters may be entered in any order. All entries are checked for errors and displayed on the front panel. Current parameter settings may be checked by pressing the corresponding button on the front panel. Up to 80 complete sets of programming may be stored in the generator and rapidly recalled.

The Wavetek Model 270 Programmable Function Generator can be controlled by the HP-85 Microcomputer over the Hewlett-Packard Interface Bus (HP-IB). The handshaking and

data transfer is accomplished as discussed in Chapter 2. The Model 270 is controlled by sending commands over the GPIB data lines. The function generator interprets the commands and responds as directed. When the function generator is directed by the computer to send data, it uses the same data lines that the computer used to send commands. Table I is a partial list of function codes used by the computer to control the function generator.

TABLE I

Wavetek Function Generator Programming Commands

Control and data Names	Model 270 Key	ASCII (GPIB) Character
Change Sign	+/-	-
Decimal Point	.	.
0,1,...,9	0,1,...,9	0,1,...,9
Amplitude	AMPL	A
Mode	MODE	B
Function	FUNC	C
Offset	OFST	D
Exponent	EXP	E
Frequency	FREQ	F
Execute	EXEC	I
Output On/Off	ON	P
Recall Setting	RCL	Y
Reset	RST	Z
GPIB Address	ADRS	----

The computer and function generator are connected using the HP-IB. The function generator's factory-set address can be found by pressing the "ADRS" button on the front panel. If some other address is desired it can be entered from the front panel by pressing "ADRS", entering desired address and pressing "EXEC". The address must be used in all computer-to-generator communications. The function generator output is connected to provide waveforms to desired destinations (an oscilloscope is good for demonstration purposes), the computer program is loaded, and the system is ready for operation.

The sample program provided in Appendix B, was written to provide a simple hands-on means of system familiarization. It does not demonstrates all the Model 270's capabilities. To use the sample program configure a system such as the one shown in Figure 3.1. A simplified flow diagram of the program is shown in Figure 3.2.

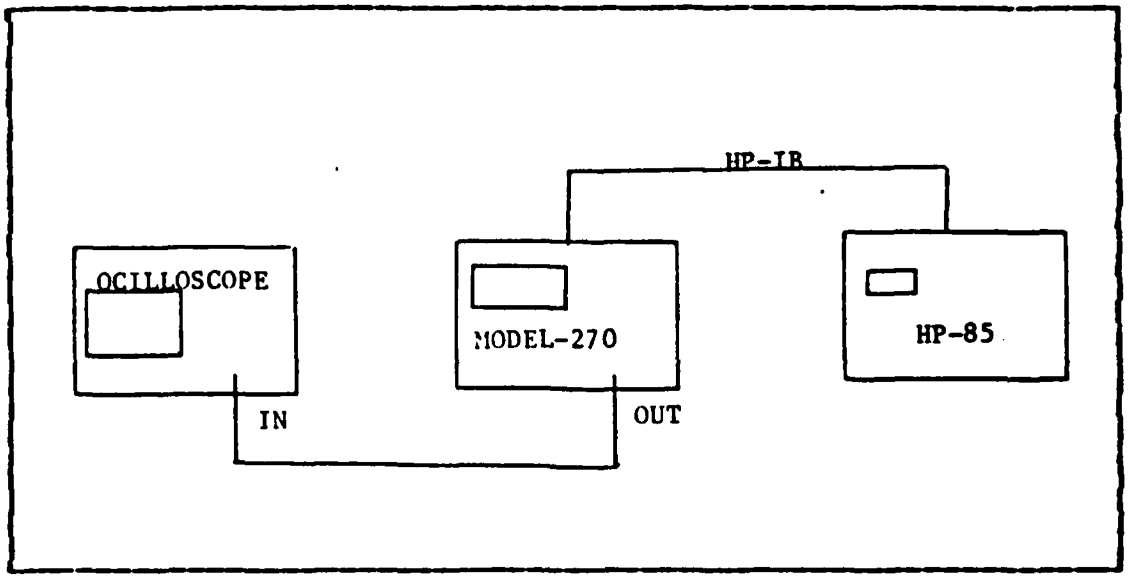

Figure 3.1 Model 270 Demonstration.

When the program is initiated the computer display will provide instructions for entering a function into the function generator. The user should respond to the displayed questions. The "END LINE" key is used to enter the user's response into the computer. Numbers may be entered using integer (e.g.,"1000"), floating point (e.g.,"15.2"), or exponential (e.g.,"1E6") forms. The user will be asked to enter waveform type, amplitude, frequency, and DC offset. As each entry is made, the Wavetek Function Generator display will show that entry. After a function has been

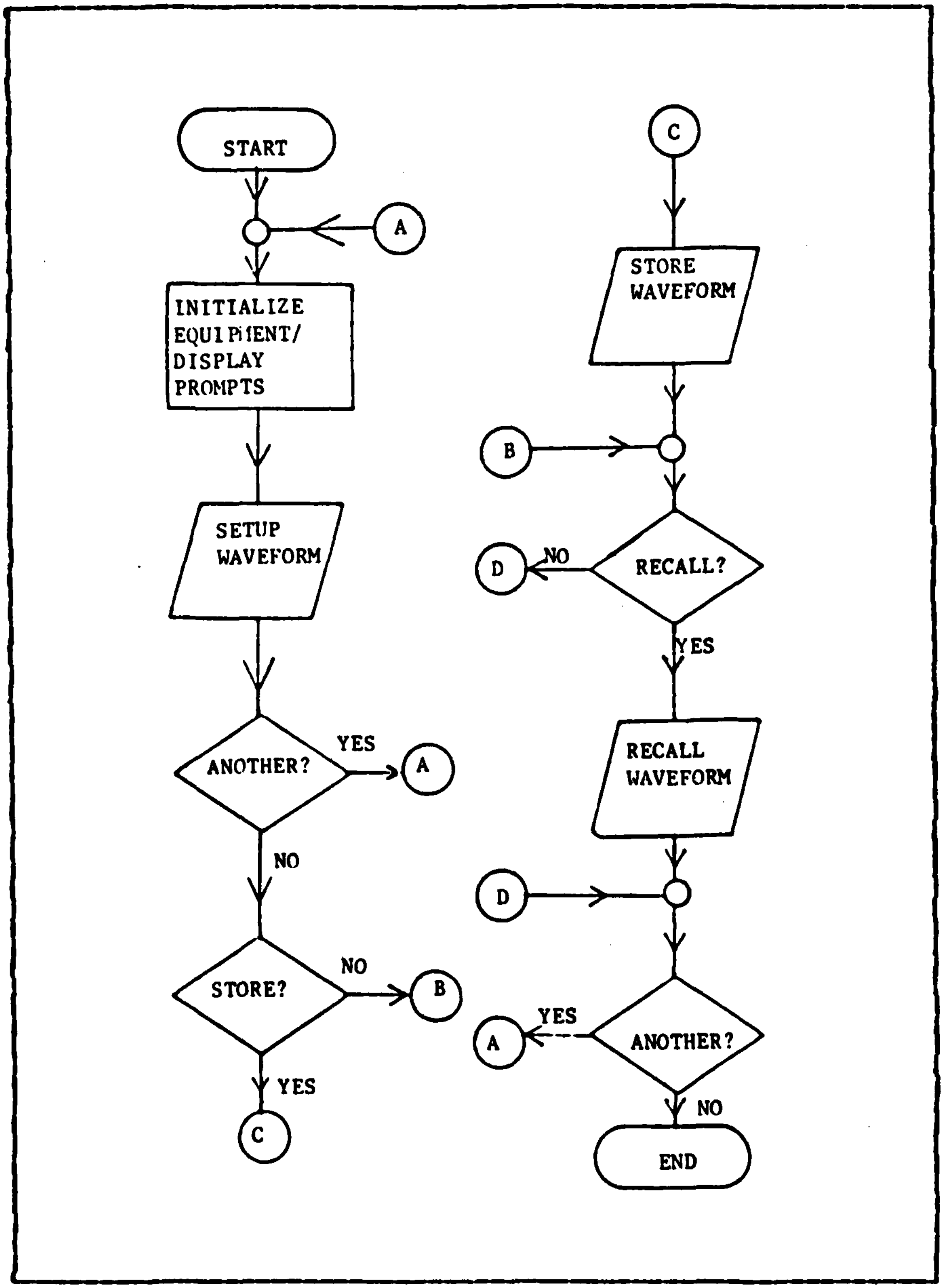

Figure 3.2 Wavetek 270 Demonstration Program Flow Diagram.

fully selected, the function will be gated to the function generator output and displayed on the oscilloscope, and the computer will query the function generator as to its status. The function generator's response will be printed on the computer's printer.

The sample program also contains a section on the use of the function generator's memory. It allows the user to store functions in the Model 270's memory and to recall and display previously stored functions. This demonstrates the ability of the Wavetek function generator to store and recall up to eighty waveforms.

For a more detailed description of the function generator's capabilities, the user should refer to the Instruction Manual for the Wavetek Model 270, Programmable Function Generator [Ref. 2].

C. PS 5010 PROGRAMMABLE POWER SUPPLY

The Tektronix PS 5010 Programmable Power Supply provides a floating dual supply and a ground-referenced logic supply. Each supply has independent constant voltage modes or constant current modes with automatic crossover.

The floating supply provides 0 to +32 volts DC and 0 to -32 volts DC, both with respect to a common front panel terminal. All floating supply terminals can be elevated above ground to a maximum 150 volts peak. Voltage differences from 0 to 64 volts are available across the dual supply terminals. The floating point supplies are programmable in increments of 10 millivolts from 0 to 10.0 volts and in increments of 100 millivolts from 10.1 volts to 32.0 volts. The current is programmed in 50 milliamp increments from 50 milliamps to 1.5 amps.

The logic supply provides 4.5 volts DC to 5.5 volts DC at currents to 3 amps. The logic supply is programmable in increments of 10 millivolts from 4.50 volts to 5.50 volts and in current increments of 100 milliamps over a range of 100 milliamps to 3 amps.

The front panel LED display is divided into three sections. Each section indicates the programmed current or voltage for one supply. In the operating mode, the displays show the true output voltage when operated in the constant voltage mode or current when operated in the constant current mode. A more complete description of the PS 5010 specifications can be found in Ref. 3.

Table II is a condensed list of commands used by a system controller to direct the PS 5010.

A demonstration for the PS 5010 and the DM 5010 combination is included in Appendix B. This program is discussed in the following section covering the DM 5010 Programmable Digital Multimeter.

D. DM 5010 PROGRAMMABLE DIGITAL MULTIMETER

The Tektronix DM 5010 Programmable Digital Multimeter measures and displays dc voltages, resistance, true rms ac voltages, and voltages consisting of a dc level plus an ac waveform. Range selection is automatic or manually incremented. A diode test function provides a 1 milliamp current output for diode testing. Measurements are made via front-panel connectors or a rear-interface connector.

The DM 5010 also performs calculation for averaging, scale and offset, conversion to dBm or reference dB, and comparison. Measurements and calculations are indicated on a signed 4 1/2 digit LED display. The decimal point is automatically positioned and leading zeros are blanked.

TABLE II

PS 5010 Commands and Descriptions

Header	Argument	Description
ERR		Returns error code
ILOG	<num>	Sets the logic supply current limit
INEG	<num>	Sets negative floating supply current limit
INIT		Resets instrument settings to power-on state
IPOS	<num>	Sets positive floating supply current limit
OUT	ON	Connects all supplies to the output terminals
SET?		Returns instrument settings
VLOG	<num>	Sets logic supply voltage limit
VNEG	<num>	Sets negative floating supply voltage limit
VPOS	<num>	Sets positive floating supply voltage limit
VLOG? VNEG? VPOS?		Returns setting for respective supply (i.e. VNEG <num>)

The operation of the DM 5010 is programmable via high-level commands (ASCII) sent over the GPIB. The DM 5010 can send information about front panel control settings, measurements, and calculations via the bus to the GPIB controller. Measurements and calculations are triggered by internal circuitry (at a normal or fast rate), front panel push button, GPIB command, or external signal via the rear-interface connector. A more detailed description of the DM 5010 specifications and operating instructions can be found in Ref. 4.

Table III is a condensed list of commands used to control the DM 5010 via the GPIB.

TABLE III

DM 5010 Commands and Descriptions

Header	Argument	Description
ACDC	<num>	selects the ACV+DCV function. Argument selects range.
ACV	<num>	selects the ACV function. Argument selects range.
DCV	<num>	Selects the DCV function Argument selects range.
ERR?		Returns error code.
FUNCT?		Returns the current function and range.
INIT		Initializes to power-on settings
OHMS	<num>	Selects OHMS function. Argument selects range.
SEND		Returns latest measurement.

Note: negative or omitted argument selects auto-range capability.

A demonstration program for the PS 5010 Programmable Power Supply and the DM 5010 Programmable Digital Multimeter is included in Appendix B. A simplified flow diagram for this program is shown in Figure 3.3. To run the program the system is configured as shown in figure 3.4. The program is loaded and run in the HP-85 computer following the instructions displayed on the screen. The program guides the user through the setup of each of the PS 5010's voltage supplies. At each step the DM 5010 will measure and display the voltage level. The computer will also read the DM 5010 and print the reading on the printer. A WAIT 1000 (1 second delay) command is used in the program just before the computer reads the meter. This delay ensures that the computer will not try to read the meter before the reading has settled. Reference 4 shows the maximum settling time when reading AC volts (true RMS) to be 1.2 seconds. Table IV shows a sample printout.

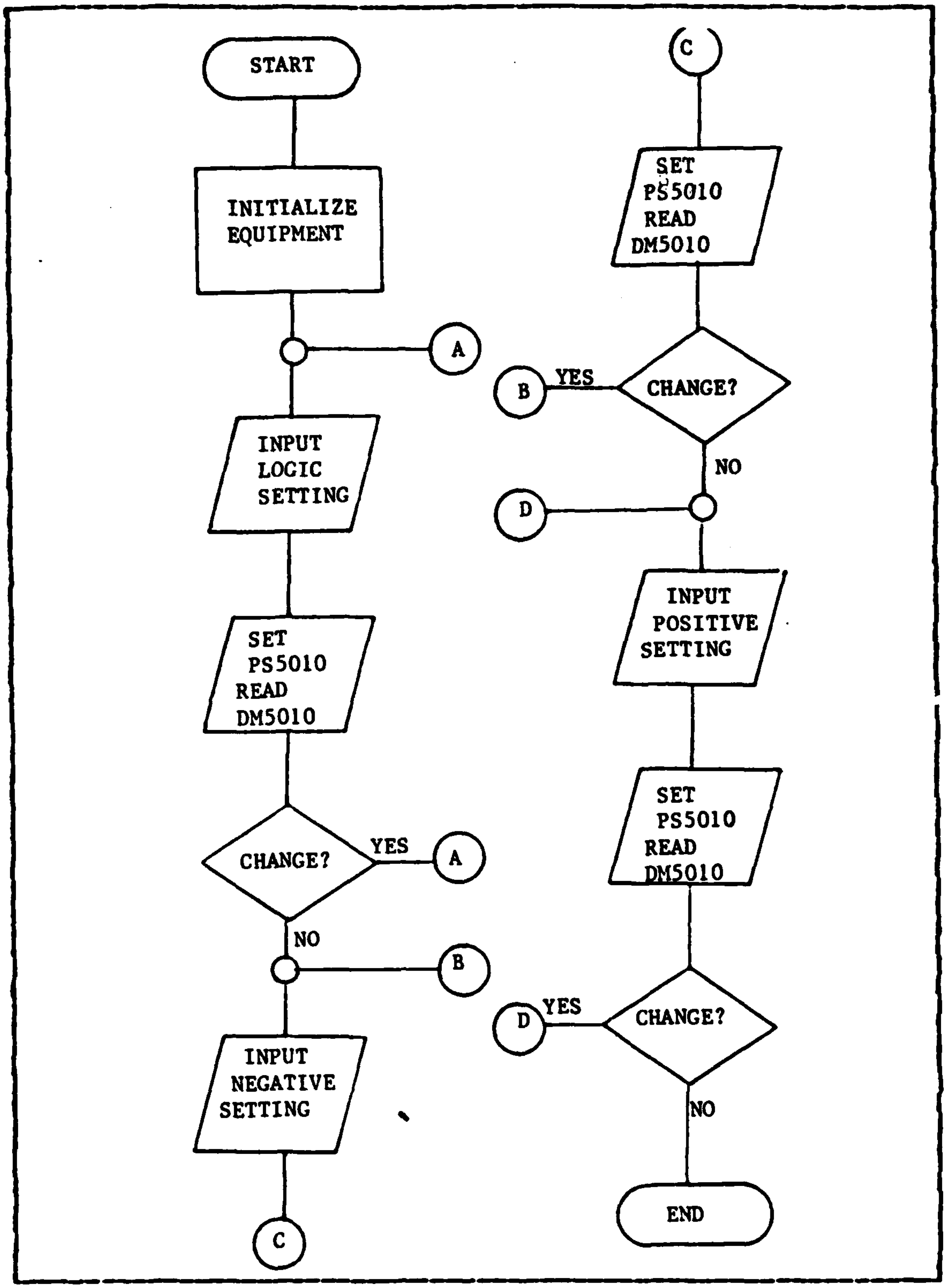

Figure 3.3 PS 5010 and DM 5010 Demonstration Flow Diagram.

TABLE IV

PS 5010 and DM 5010 Demonstration Program Printout

LOGIC VOLTAGE IS:	4.9
NEGATIVE VOLTAGE IS:	-17.5
POSITIVE VOLTAGE IS:	24.4

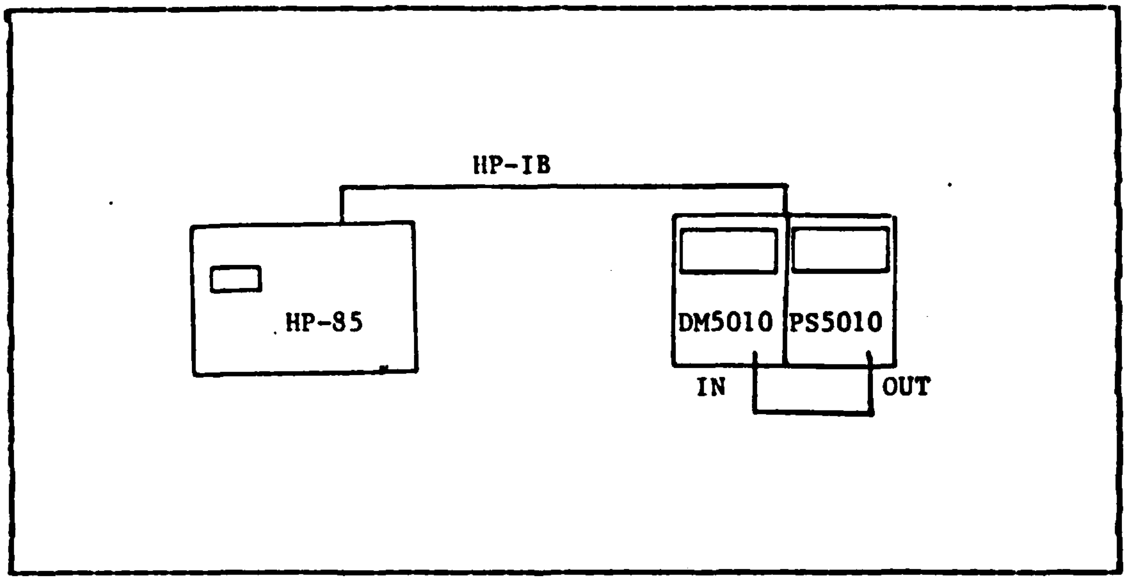

Figure 3.4 PS 5010 and DM 5010 Demonstration Setup.

This discussion and the demonstration program cover only a small percentage of the DM 5010's capabilities. For more details refer to the programming manual [Ref. 4].

E. OTHER GPIB EQUIPMENT

This section discusses equipment which was not incorporated in the research discussed in later chapters, but which might have uses in future research.

1. The Photodyne Model 488XLI GPIB Interface and Model 22XLA Fiber Optic Multimeter

The Photodyne Model 488XLI GPIB Interface Adaptor provides the logic and control functions necessary to interface the Model 22XLA Fiber Optic Multimeter with a GPIB controller. The combination of the 488XLI and 22XLA can operate in either the talk-only or addressable mode, as determined by the setting of an internal switch. In the talk-only mode, it can send data to a GPIB compatible listener at one of eight switch selectable rates, from 2.5 readings a second to one reading per hour. In the addressable mode, readings may be triggered or non-triggered, depending on whether its odd or even address is received from the controller. The Model 488XLI provides an output of ASCII data, sign, and terminator. A short demonstration program is provided in Appendix B. The 488XLI and 22XLI combination is very easy to use and program.

2. Hewlett-Packard 1615A Logic Analyzer

The Hewlett-Packard 1615A Logic Analyzer offers asynchronous timing diagram measurements and synchronous state measurements for use in the design and troubleshooting of digital systems. Measurement setups are simplified with a menu system which reduces the number and complexity of front panel keys. With the format specification menu, the desired mode of operation: timing, state, or simultaneous dual-mode, is selected. The corresponding trace specification menus then allow entry of the desired triggering and data parameters.

The 1615A Logic Analyzer was found to be not completely compatible with the HP-85 Computer. Using the HP-85 as system controller, it was possible to set all parameters into the 1615A, but data could not be transferred from the 1615A to the HP-85. The problem in data transfer

seems to be one of a not fully compatible handshake. When the HP-85 directs the 1615A to send its data, the 1615A goes to the talk mode and places the first byte of data on the bus, however the DAV (data valid) line is not set. Since the HP-85 does not receive DAV it does not accept the first byte of data and the entire system locks up with neither the HP-85 nor the 1615A responding to keyboard inputs.

Hewlett-Packard engineers who were consulted on this problem suggested that this problem might be circumvented by directing the 1615A to transfer its data to a printer or buffer space rather then to the HP-85 directly. Further research is needed to see if this solution will work. The 1615A Logic Analyzer would be a very valuable piece of equipment for basic digital laboratories. Efforts should be made to solve the compatibility problem or to find a compatible controller.

3. Hewlett-Packard 9111A Graphics Tablet

The Hewlett-Packard 9111A Graphics Tablet is used to input coordinate points to the microcomputer. It also has sixteen menu softkeys to allow option selection away from the computer keyboard.

It was thought that the Graphics Tablet could be used to annotate computer generated plots, however this proved not to be very workable due to the small screen on the HP-85 computer. A demonstration program, included in Appendix B, provides an introduction to the 9111A and its uses.

4. The Hewlett-Packard 59401A Bus System Analyzer

The HP-59401A Bus System Analyzer is invaluable as an aid to GPIB users in hardware design and in diagnosis of hardware and software problems encountered in GPIB compatible systems. When in the listen mode the 59401A monitors Bus traffic and can accept and store up to 32 characters

from the bus for later examination. It can slow down data transfer and handshaking so they may be observed. When used in the talk mode the 59401A is used to drive the Bus. The Bus can be driven one character at a time by setting the DIO switches to the appropriate code and outputting this information to the Bus.

While the 59401A Bus System Analyzer is not itself a piece of programmable test equipment, its importance in setting up and testing a GPIB system cannot be overstated. The ability to observe and control the handshake and data transfer lines on the bus greatly simplifies the design and trouble-shooting processes.

5. Wavetek DC 5009 Universal Counter/Timer

The Tektronix DC 5009 Universal Counter/Timer features reciprocal frequency, period, counting events on channel B during time gates applied to channel A and totalizing measurements to 135 MHz. It also has time interval and width features of 10 ns resolution for timing measurements. For repetitive timing measurements, averaging and pseudo-random time base modulation circuitry provides increased accuracy over a wide range of input signals. The DC 5009 provides trigger level outputs at both the front panel and rear interface for increased measurement convenience.

The DC 5009 is GPIB programmable and allows any manually selectable function or mode to be operated over the GPIB bus, including all input conditioning controls. After the DC 5009 is set to the remote state by a system controller, its operating modes and settings can be set and read by programming mnemonics sent to it in ASCII code over the bus. The instrument settings may also be read while in the local state. The DC 5009 connects to the bus through a GPIB-compatible connector on the TM 5000-series power module.

Measurement results are displayed in an eight-digit LED readout, with the decimal point automatically positioned. The displayed count overflow is indicated by a flashing display. The counter also uses three digits of the seven-segment LED display to indicate internal or operating error codes and two digits for external signal probe compensation results.

Table V is a condensed list of commands used with the DC 5009. A more detailed description of the Counter/Timer's specifications and operating procedures can be found in Ref. 5.

TABLE V

DC 5009 Commands and Description

Commands	argument	Description
AUTO		Sets trigger level to signal midpoint (both channels).
AVE	<num>	Sets number of measurements averaged.
CHA	A or B	Selects channel for succeeding input settings.
EVE	(BA)	Counts Channel B during Channel A pulse width.
FREQ	(A)	Measures frequency of input signal on Channel A.
INIT		Resets to current front-panel settings and power-on parameters.
PER	(A)	Measures the period of Channel A signal.
RAT	(B/A)	Measures ratio of B events to A events.
SEND		Obtains and formats new measurement results.
SET?		Query returns current instrument settings.
TIME	(AB)	Measures time from A event to B event.
WID	(A)	Measures pulse width of channel A signal

IV. DATA COLLECTION

In the previous chapter several GPIB programmable test equipments were introduced. In this chapter it will be shown how combinations of those equipments can be used to conduct basic electronics laboratory measurements. A student in a basic electronics class, such as EC-2211 at the Naval Postgraduate School, might be asked to build and evaluate the frequency response of a simple common-emitter amplifier similar to the one shown in Figure 4.1.

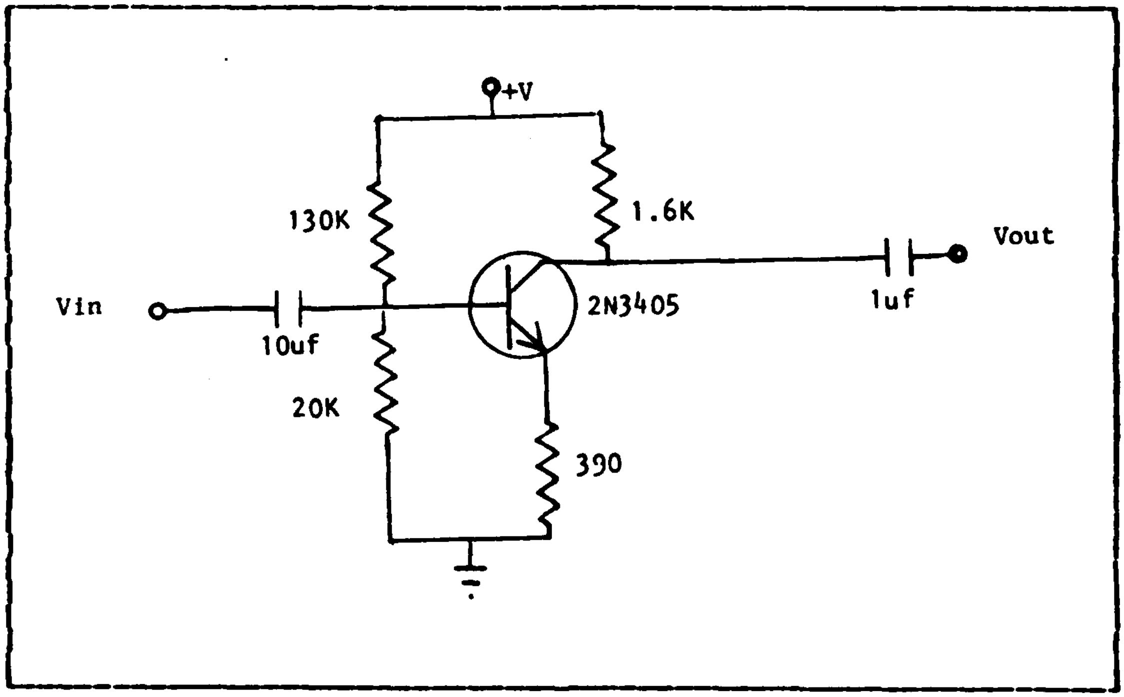

Figure 4.1 Common-Emitter Amplifier.

To complete an evaluation of his circuit performance he would need a signal generator, power supply, frequency counter, AC voltmeter, and an oscilloscope. He would need

to become familiar enough with each of these equipments to ensure that any data obtained from his tests was correct. Problems incountered must first be investigated for equipment setup problems.

A greatly simplified procedure for investigating the same common-emitter amplifier would use programmable test equipment and a microcomputer controller. A program would insure proper equipment setup and could even perform a check to verify a proper circuit to be tested. This check would help the student identify problems in his circuit before time was lost in taking useless test data. Finally the microcomputer controlled test could take a greater number of data points at a much faster rate.

To test a common-emitter amplifier and obtain a printout of frequency and gain, the following test equipment could be used: HP-85 Microcomputer, Model 270 Function Generator, PS 5010 Power Supply, and the DM 5010 Digital Multimeter. The equipment configuration for this type of an experiment is shown in Figure 4.2.

A sample program for the HP-85 Microcomputer which uses the equipment as configured in Figure 4.2 to test a common-emitter amplifier is included in Appendix B. The program uses the Wavetek Model 270 Function Generator to provide a known input to the circuit under test. The Model 270 is shifted through a range of frequencies at a constant voltage. At each frequency the test circuit's output voltage is read by the DM5010. The HP-85 Computer computes the gain at each frequency using the DM5010 readings and the known input voltage value. A simplified flow diagram for this program is shown in Figure 4.3. This program allows the user to select power supply voltages, frequency range, and number of data points to be taken. It prints out the

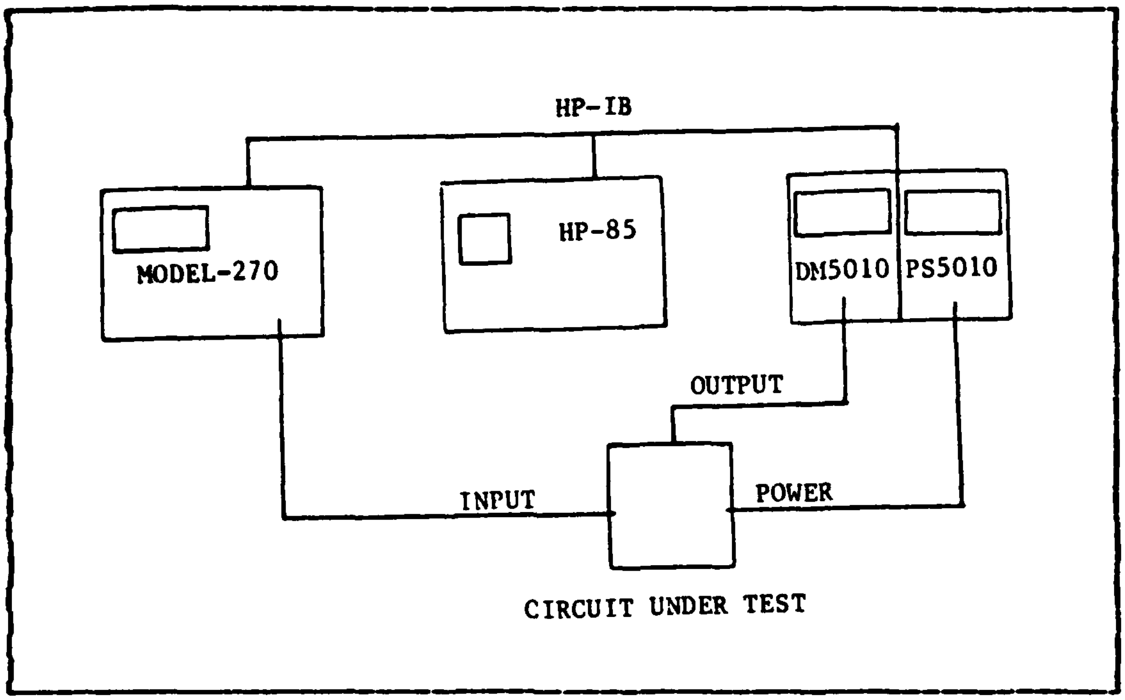

Figure 4.2 Equipment Setup for C-E Amplifier Test.

frequency and gain (in dB) for each point. All user entries are made from the HP-85 keyboard in response to displayed questions. A sample of the type of output generated is shown in Table VI .

The sample program is not limited to use with simple common-emitter amplifiers; it can test the frequency-vs-gain characteristics of any desired circuit, such as an amplifier or filter. A frequency counter is not needed due to the good frequency accuracy of the Model 270 Function Generator (but could easily be incorporated in the measurement system). Many more advanced electronics courses could use the same test equipment and program for frequency-vs-gain characteristics.

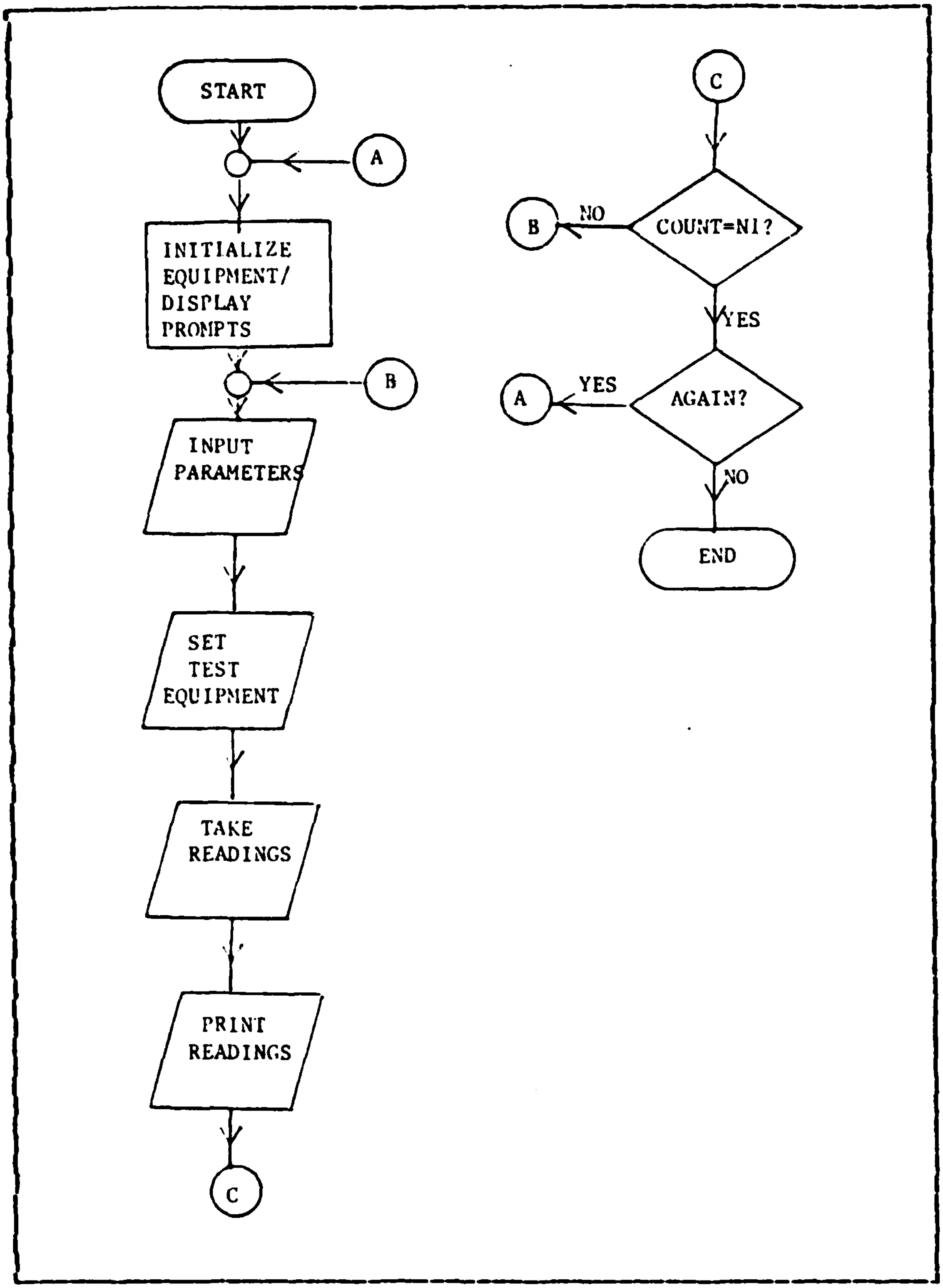

Figure 4.3 Data Printout Demonstration Program Flow Diagram.

TABLE VI

Sample Output from Freq-Gain Program

```
FREQUENCY-vs-GAIN
FREQ:           GAIN:
    10.0Hz  -182.82dB
 50009.0Hz    36.25dB
100008.0Hz    35.50dB
150007.0Hz    34.90dB
200006.0Hz    34.27dB
250005.0Hz    33.51dB
300004.0Hz    32.65dB
350003.0Hz    32.65dB
400002.0Hz    30.44dB
450001.0Hz    29.18dB
500000.0Hz    27.53dB
549999.0Hz    25.50dB
599998.0Hz    24.03dB
649997.0Hz    20.70dB
699996.0Hz    20.70dB
749995.0Hz    18.81dB
799994.0Hz    16.11dB
849993.0Hz    11.78dB
899992.0Hz     6.11dB
949991.0Hz     -.28dB
```

V. DATA DISPLAY

In the previous chapter it was shown how computer controlled test equipment could obtain faster, more accurate test data. If this was all the computer could do it would be a major savings of time, however the computer can also provide a display of the data.

A. HP-85 GRAPHICS CAPABILITIES.

The HP-85 Microcomputer provides two different display areas or modes: alphanumeric and graphics. Normally the display is in the alpha mode, but the user can view the current graphics display at any time by pressing the "GRAPH" key or by executing the statement, GRAPH. The graphics capability of the HP-85 enable the user to:

(1) Plot data on the graphics display, thus clarifying a complex set of information in pictorial form.

(2) Scale the display to desired proportions.

(3) Generate a number of lines, curves, diagrams and designs on the display.

(4) Copy anything from the graphics display to the printer with one command.

(5) "Draw" and label graphs with ease.

(6) Interact with the graphics display from the keyboard.

(7) Execute any graphics command from the keyboard or in a program.

If the HP-85 is equipped with the Printer/Plotter ROM, graphics programs for the HP-85 can be plotted directly on the Hewlett-Packard 7470A Plotter by using the "TRANSLATE" command.

In Chapter 4 it was shown how the frequency verses gain characteristics for a common-emitter amplifier could be measured and printed. The same data could be plotted by the HP-85 directly. This would provide the student with a quick graphical display of the amplifiers gain characteristics. Included in Appendix B is a program which will test the amplifier, print frequency and gain for each test point, graph the data, and copy the graph on the printer. Figure 5.1 is an example of the printed graph for the circuit shown in Figure 4.1 . A simplified flow diagram for the demonstration program is shown in Figure 5.2

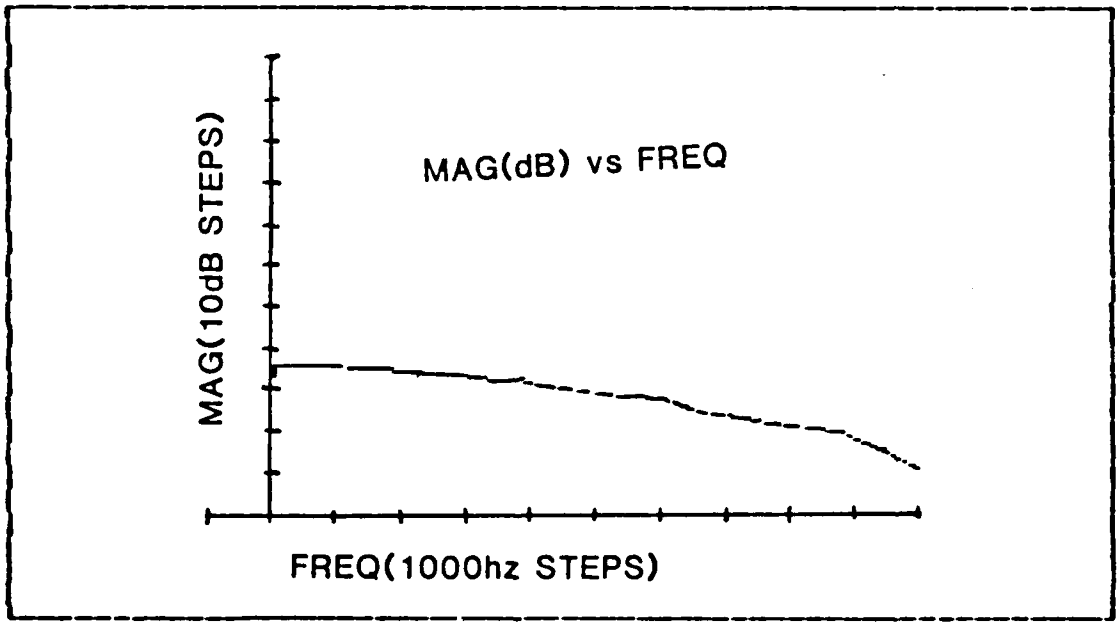

Figure 5.1 C-E Amplifier Characteristics.

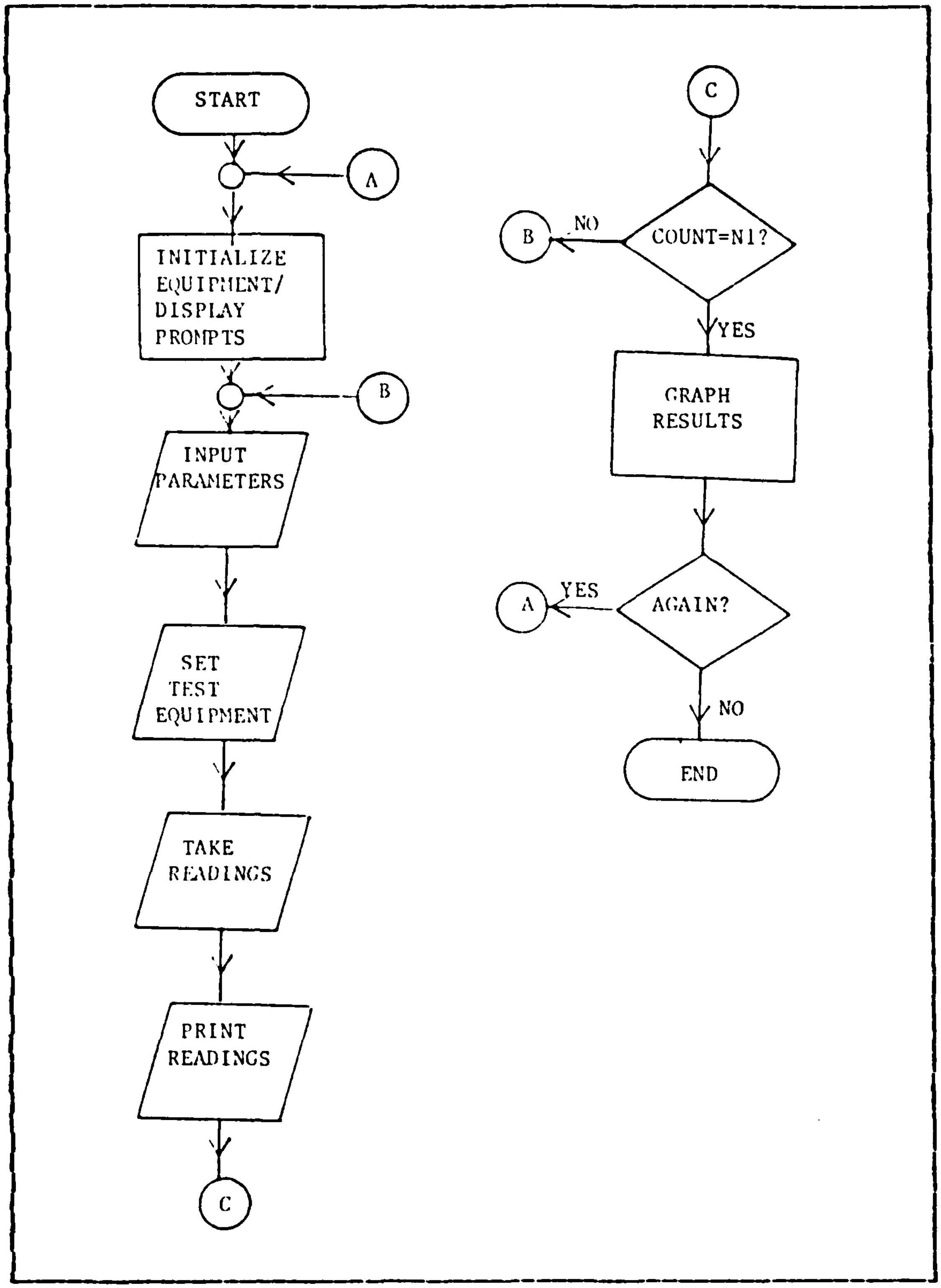

Figure 5.2 Graphics Demonstration Program Flow Diagram.

As was previously discussed this type of program is not limited to testing one circuit. More complex circuits can also be tested using the same program. Figure 5.3 is an example of a Butterworth bandpass filter.

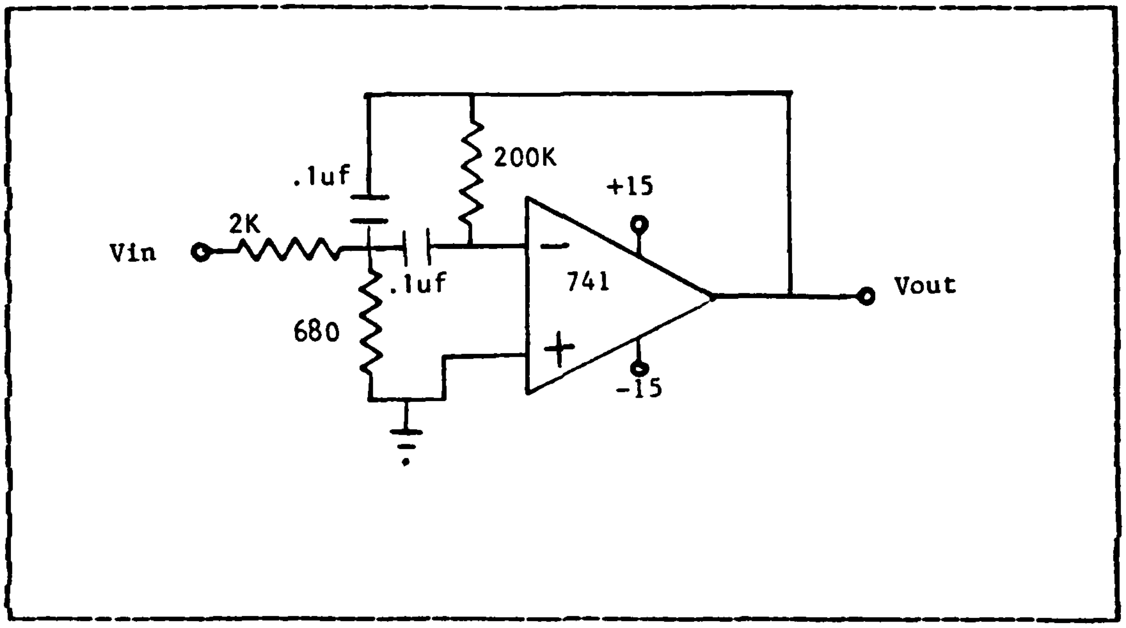

Figure 5.3 Butterworth Bandpass Filter.

Figure 5.4 shows the printed output for the circuit shown in Figure 5.3 using the same program that was used to test the common-emitter amplifier.

B. VISICALC PLUS

For some graphics applications, such as a logarithmic graph, a simple HP-85 program is not sufficient. For extensive or specialized graphics a pre-written graphics program package is desirable; one such program is the Hewlett-Packard VisiCalc Plus package. Briefly the HP-87 VisiCalc Plus package is a group of graphics and calculation programs for the HP-86/87 Microcomputers. The package contains the following programs:

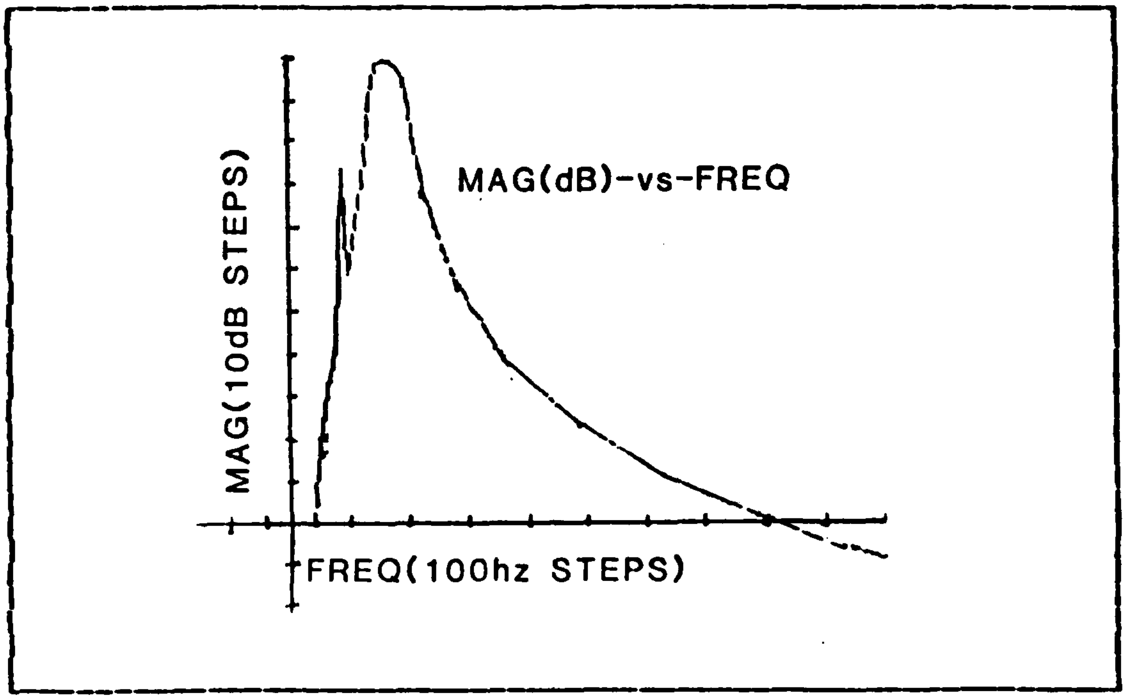

Figure 5.4 BP Filter Characteristics.

VZCALC: A binary program that is the main VisiCalc program.

VZLINE: A BASIC program that uses VisiCalc data to graph line charts.

VZCURV: A BASIC program that allows you to fit standard regression curves to VisiCalc data.

VZPIE: A BASIC program that uses VisiCalc data to plot pie charts.

VZBAR: A BASIC program that uses VisiCalc data to create bar charts.

LINCURg: A binary program that is automatically loaded and executed by the four graphics programs.

REDZERg: A binary program that is automatically

loaded and executed by VZLINE, VZCURVE, and VZBAR.

VZREAD: A BASIC program that allows you to read data files created by VisiCalc.

VZWRITE: A BASIC program that allows you to create VisiCalc data files from numeric arrays.

A detailed description of VisiCalc Plus can be found in Ref. 6.

The HP-87 version of VisiCalc Plus was used to generate the graphs shown in Figures 5.5 and 5.6. A HP-85 version of VisiCalc Plus is available, but was not tested in this study. In order to use VisiCalc Plus to plot the common-emitter amplifier data, the data must be put on disk as a numeric data array. An HP-85 program to take the data samples and write them on a disk correctly formatted is provided in Appendix B. Once the data is on disk it can be used by VisiCalc Plus on a HP-86 or HP-87 microcomputer system. VZWRITE is used to create a VisiCalc data file from the data on the disk. Figures 5.5 and 5.6 show VisiCalc graphs of the common-emitter amplifier data.

Many graphics programs such as VisiCalc Plus are available for data display. The Standard Programming Package for the HP-85 Microcomputer contains some graphics programs which could be used to display acquired test data.

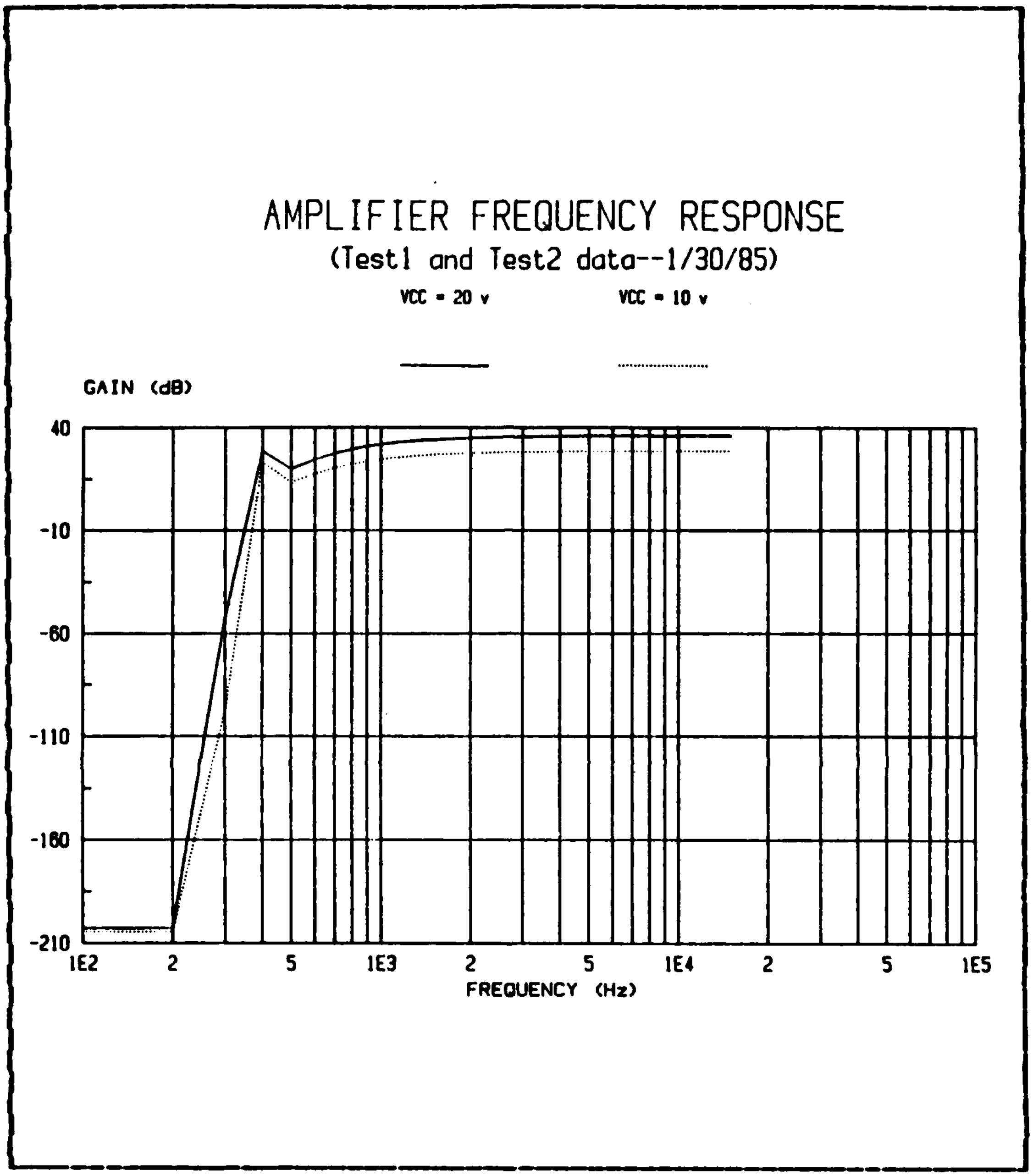

Figure 5.5 C-E Amplifier, Low Frequency.

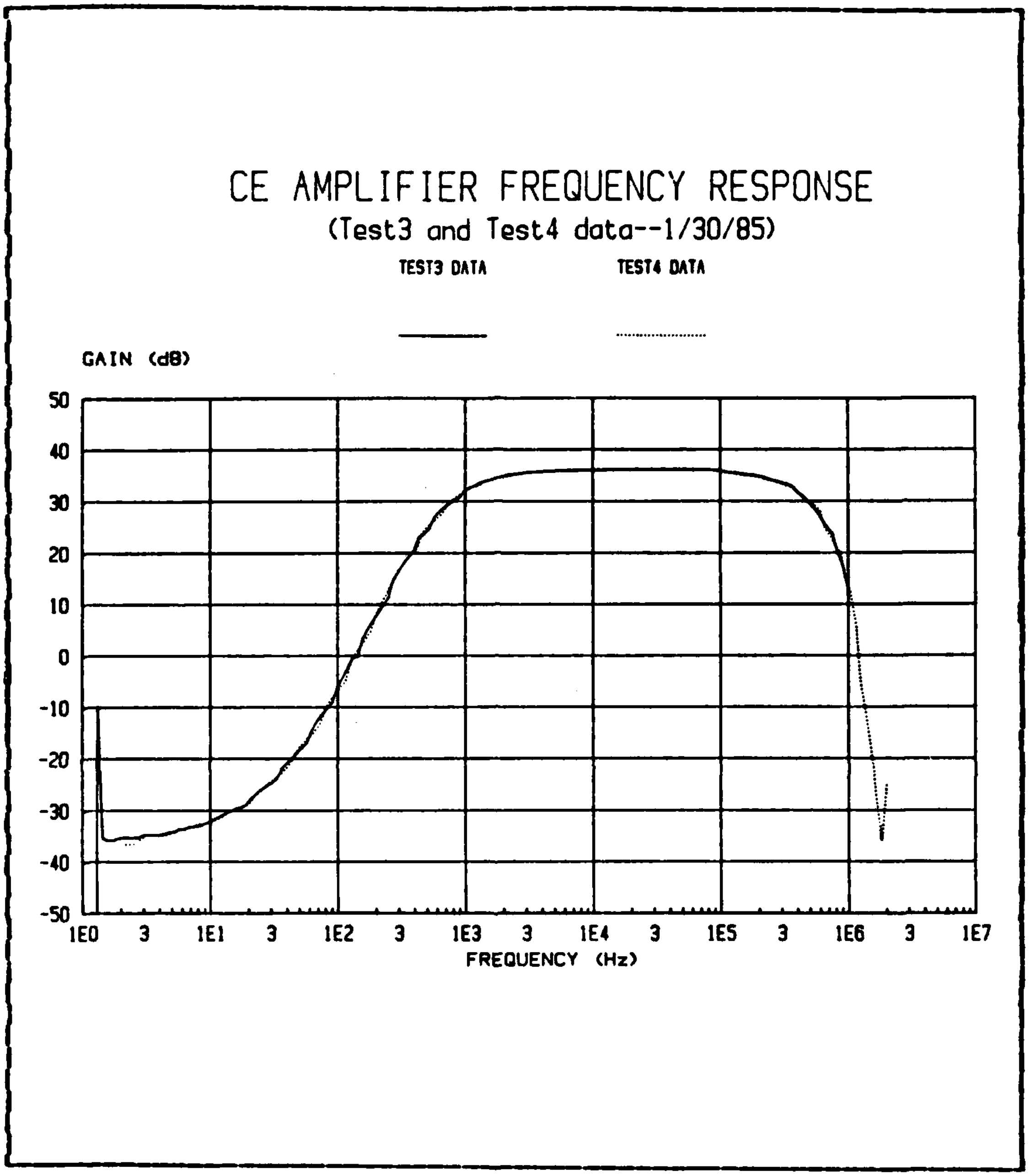

Figure 5.6 C-E Amplifier, High Frequency.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

It has been demonstrated, for at least a simple experiment, that programmable test equipment could replace the presently used manually operated test equipment. The question that must be answered is, whether replacing current test equipment with programmable test equipment is a good decision in terms of cost compared to benefits received? As has been previously discussed, some of the benefits of a computer controlled system over conventional manual methods are:

(1) More consistent results in repeated measurements, since a computer controlled system is not subject to operator fatigue.

(2) Greater throughput because systems are generally faster.

(3) More thorough testing because system speed allows more parameters to be measured in a shorter time.

(4) Results expressed in engineering or scientific units, since many system controllers are capable of on-line data manipulation.

(5) Greater accuracy because system errors can be measured automatically, stored and accounted for in the results.

(6) Adaptive data acquisition where a system can be programmed to branch to other measurements to help pinpoint the problem when it senses an abnormal condition.

(7) Measurement results can be stored in computer memory, on disk or tape, or on hard copy.

(8) Computer graphics and plotting provide improved data presentation capabilities.

(9) Students would gain some familiarity with the uses and operation of a microcomputer.

Some of the disadvantages of a computer controlled system are:

(1) Cost, since computer-controlled test equipment systems are currently much more expensive then manually operated test equipment. A quick study of Ref. 8 shows HP-IB compatible test equipment to be from two to five times as expensive as similar test equipment without the HP-IB option.

Hewlett-Packard has recently (May, 1985) introduced a new line of programmable test equipment called the PC Instruments system. This equipment is not GPIB compatible without optional hardware, but it does provide computer-controllable test equipment using a different bus structure. The cost of this equipment is roughly twice that of manual test equipment. Hewlett-Packard has software available for several of thier computer types for use with this equipment.

(2) Students would not be required to be as familiar with the test equipment if it is computer-controlled.

(3) Students could complete a experiment in a cookbook fashion and not really understand what they are doing.

B. RECOMMENDATIONS

Based on this study the following recommendations are made:

(1) As replacement test equipment is needed, the replacements should be GPIB compatible. The large cost difference between GPIB compatible and manually operated test equipment should become less as GPIB equipment becomes more common. The advantages of computer controlled systems discussed in the previous section are greater then the disadvantages.

(2) Software development should begin immediately covering all the basic electronics laboratories. If the software development is done now it would be available and tested before the equipment is purchased. Even if the decision is made not to purchase GPIB compatible equipment, the software development would be worthwhile material for future thesis students.

(3) Other GPIB compatible test equipment should be purchased and tested. This would ensure that future purchases of large numbers would be based on in-house research and not on slick salesmanship. Also other equipments could lead to uses not currently anticipated.

APPENDIX A

ASCII & IEEE 488 (GPIB) CODE CHART

B7 B6 B5 / BITS B4	B3	B2	B1	0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
				CONTROL		NUMBERS SYMBOLS		UPPER CASE		LOWER	
0	0	0	0	0 NUL 0 (0)	20 DLE 10 (16)	40 SP 20 (32)	60 0 30 (48)	100 @ 40 (64)	120 P 50 (80)	140 ` 60 (96)	160 p 70 (112)
0	0	0	1	1 GTL SOH 1 (1)	21 LLO DC1 11 (17)	41 ! 21 (33)	61 1 31 (49)	101 A 41 (65)	121 Q 51 (81)	141 a 61 (97)	161 q 71 (113)
0	0	1	0	2 STX 2 (2)	22 DC2 12 (18)	42 " 22 (34)	62 2 32 (50)	102 B 42 (66)	122 R 52 (82)	142 b 62 (98)	162 r 72 (114)
0	0	1	1	3 ETX 3 (3)	23 DC3 13 (19)	43 # 23 (35)	63 3 33 (51)	103 C 43 (67)	123 S 53 (83)	143 c 63 (99)	163 s 73 (115)
0	1	0	0	4 SDC EOT 4 (4)	24 DCL DC4 14 (20)	44 $ 24 (36)	64 4 34 (52)	104 D 44 (68)	124 T 54 (84)	144 d 64 (100)	164 t 74 (116)
0	1	0	1	5 PPC ENQ 5 (5)	25 PPU NAK 15 (21)	45 % 25 (37)	65 5 35 (53)	105 E 45 (69)	125 U 55 (85)	145 e 65 (101)	165 u 75 (117)
0	1	1	0	6 ACK 6 (6)	26 SYN 16 (22)	46 & 26 (38)	66 6 36 (54)	106 F 46 (70)	126 V 56 (86)	146 f 66 (102)	166 v 76 (118)
0	1	1	1	7 BEL 7 (7)	27 ETB 17 (23)	47 ' 27 (39)	67 7 37 (55)	107 G 47 (71)	127 W 57 (87)	147 g 67 (103)	167 w 77 (119)
1	0	0	0	10 GET BS 8 (8)	30 SPE CAN 18 (24)	50 (28 (40)	70 8 38 (56)	110 H 48 (72)	130 X 58 (88)	150 h 68 (104)	170 x 78 (120)
1	0	0	1	11 TCT HT 9 (9)	31 SPD EM 19 (25)	51) 29 (41)	71 9 39 (57)	111 I 49 (73)	131 Y 59 (89)	151 i 69 (105)	171 y 79 (121)
1	0	1	0	12 LF A (10)	32 SUB 1A (26)	52 * 2A (42)	72 : 3A (58)	112 J 4A (74)	132 Z 5A (90)	152 j 6A (106)	172 z 7A (122)
1	0	1	1	13 VT B (11)	33 ESC 1B (27)	53 + 2B (43)	73 ; 3B (59)	113 K 4B (75)	133 [5B (91)	153 k 6B (107)	173 { 7B (123)
1	1	0	0	14 FF C (12)	34 FS 1C (28)	54 , 2C (44)	74 < 3C (60)	114 L 4C (76)	134 \ 5C (92)	154 l 6C (108)	174 | 7C (124)
1	1	0	1	15 CR D (13)	35 GS 1D (29)	55 − 2D (45)	75 = 3D (61)	115 M 4D (77)	135] 5D (93)	155 m 6D (109)	175 } 7D (125)
1	1	1	0	16 SO E (14)	36 RS 1E (30)	56 . 2E (46)	76 > 3E (62)	116 N 4E (78)	136 ∧ 5E (94)	156 n 6E (110)	176 ~ 7E (126)
1	1	1	1	17 SI F (15)	37 US 1F (31)	57 / 2F (47)	77 ? UNL 3F (63)	117 O 4F (79)	137 _ UNT 5F (95)	157 o 6F (111)	177 RUBOUT (DEL) 7F (127)

ADDRESSED COMMANDS

UNIVERSAL COMMANDS

LISTEN ADDRESSES

TALK ADDRESSES

SECONDARY ADDRESSES OR COMMANDS

KEY TO CHART

octal	25	PPU	GPIB code
	NAK		ASCII character
hex	15	(21)	decimal

APPENDIX B

GPIB PROGRAMS

A. WAVETEK MODEL 270 DEMONSTRATION PROGRAM

The following program provides an introduction to the Wavetek Model 270 Function Generator using the HP-85 computer as controller.

"Wavetek Function Generator"

```
10   ! program to control
20   ! Wavetek Model 270
30   ! Function Generator
40   CRT IS 1
50   ! Slave Wavetek tc HP-85
60   REMOTE 720  !assumes wavetek address is 20
70   ! Lockout Wavetek front
80   ! Panel control
90   LOCAL LOCKOUT 7
100  ! Select functicn
110  CLEAR
120  DISP "ENTER FUNCTION NUMBER"
130  DISP
140  DISP "SINE WAVE = 0"
150  DISP "TRIANGLE WAVE = 1"
160  DISP "SQUARE WAVE = 2"
170  DISP
180  INPUT C
190  OUTPUT 720; "C",C
200  ! select amplitude
210  CLEAR
220  DISP "ENTER AMPLITUDE IN VOLTS"
230  DISP "(MAX 10 V. PEAK)"
```

```
240  DISP
250  INPUT A
260  OUTPUT 720;"A",A
270  ! select frequency
280  CLEAR
290  DISP "ENTER FREQUENCY IN HZ"
300  DISP "(MAX 12MHz)"
310  DISP
320  INPUT F
330  OUTPUT 720;"F",F
340  ! select DC offset
350  CLEAR
360  DISP "ENTER DC OFFSET"
370  DISP "(+ OR - 5 V. MAX)"
380  DISP
390  INPUT D
400  OUTPUT 720;"D",D
410  ! select DC offset
420  CLEAR
430  DISP "ENTER 0 TO EXECUTE"
440  DISP "YOUR FUNCTION"
450  DISP "ENTER OTHER THEN 0"
460  DISP "TO CHANGE PARAMETERS"
470  DISP
480  INPUT B
490  IF B <> 0 THEN 110
500  OUTPUT 720; "B",B
510  OUTPUT 720; "P1I"
520  ! input status of Wavetek
530  OUTPUT 720; "XT3I"
540  ENTER 720; F,A,D,B,C,P,G
545  !print Wavetek parameters
550  PRINT "WAVETEK PARAMETERS"
560  PRINT
570  IF C=0 THEN LET C$="SINE WAVE"
```

```
580  IF C=1 THEN LET C$="TRIANGLE WAVE"
590  IF C=2 THEN LET C$="SQUARE WAVE"
600  PRINT "FUNCTION",C$
610  PRINT "FREQUENCY(Hz)",F
620  PRINT "AMPLITUDE(VOLTS)",A
630  PRINT "DC OFFSET(VOLTS)",D
640  PRINT
650  CLEAR
660  ! ask for next function
670  DISP "DO YOUT WISH TO ENTER"
680  DISP "ANOTHER FUNCTION (Y/N) ?"
690  INPUT Y$
700  IF Y$="Y" THEN 110
710  CLEAR
715  ! store function in memory
720  DISP "DO YOU WISH TO STORE"
730  DISP "YOUR FUNCTION IN MEMORY"
740  DISP "(Y/N) ?"
750  INPUT N$
760  IF N$="N" THEN 860
770  CLEAR
780  DISP "ENTER MEMORY ADDRESS"
790  DISP "(1 TO 80)"
800  INPUT M
810  OUTPUT 720; "F",F,"C",C,"A",A,"D",D,"BOP1","M",M
820  CLEAR
830  DISP "YOUR FUNCTION IS"
840  DISP "STORED IN MEMORY"
850  DISP "LOCATION:  ",M
860  DISP
865  ! recall a function from memory
870  DISP "DO YOU WISH TO"
880  DISP "RECALL AND EXECUTE"
890  DISP "A PROGRAM STORED IN"
900  DISP "WAVETEK MEMORY(Y/N) ?"
```

```
910  INPUT N$
920  IF N$="N" THEN 1130
930  CLEAR
940  DISP "ENTER MEMORY LOCATION"
950  DISP "OF STORED FUNCTION"
960  INPUT Y
970  OUTPUT 720; "Y",Y,"I"
980  CLEAR
990  DISP "FUNCTION FROM MEMORY"
1000  DISP "LOCATION:  ",Y
1010  DISP "IS NOW BEING EXECUTED"
1020  DISP
1030  DISP "DO YOU WISH TO RECALL"
1040  DISP "ANOTHER FUNCTION (Y/N) ?"
1050  DISP
1060  INPUT Y$
1070  IF Y$="Y" THEN 940
1080  CLEAR
1130  DISP "DO YOU WISH TO ENTER"
1140  DISP "ANOTHER FUNCTION (Y/N) ?"
1150  INPUT Y$
1160  IF Y$="Y" THEN 110
1170  DISP "GOODBYE"
1180  STOP
1190  END
```

B. PS 5010 AND DM 5010 DEMONSTRATION PROGRAM

This program demonstrates some of the capabilities of the Tektronix PS 5010 Programmable Power Supply and the DM 5010 Programmable Digital Multimeter. The HP-85 computer is assumed as controller. If some other controller is used, the code may need modification.

```
10   ! Program to demonstrate
20   ! the PS 5010 and DM 5010
30   ! Addresses must be
40   ! DM = 16
50   ! PS = 22
60   ! must poll PS & DM
70   ! before sending any inst.
80   ! after power up
90   S=SPOLL(716)
100  S=SPOLL(722)
115  ! set PS to power-on state
110  OUTPUT 722;"INIT"
120  PRINT
130  CLEAR
135  ! logic supply demo
140  DISP "CONNECT DM TO LOGIC SUPPLY"
150  DISP
160  DISP "ENTER LOGIC SUPPLY VOLTAGE"
170  DISP "(+4.5 TO +5.5 VOLTS)"
180  INPUT L
190  IF L>=4.5 AND L<=5.5 THEN 230
200  DISP "YOU HAVE MADE AN ERROR"
210  DISP "TRY AGAIN"
220  GOTO 150
225  ! set DM to read dc volts
230  OUTPUT 716;"DCV"
235  ! set PS logic supply
240  OUTPUT 722;"VLOG",L
```

```
245  ! turn PS output on
250  OUTPUT 722;"OUT ON"
252  ! delay to give meter time
253  ! to read voltage
255  WAIT 1000
260  ! enter meter reading
270  OUTPUT 716;"SEND"
280  ENTER 716;A$
290  PRINT "LOGIC VOLTAGE IS:"A$
300  PRINT
310  DISP
320  DISP "THE DM READING SHOULD AGREE"
330  DISP "WITH THE PRINTOUT AND THE"
340  DISP "LOGIC SUPPLY DISPLAY"
350  DISP
360  DISP "DO YOU WISH TO TRY AGAIN(Y/N)?"
370  INPUT Y$
380  IF Y$="Y" THEN 150
385  ! set PS to power-on state
390  OUTPUT 722;"INIT"
400  CLEAR
405  ! negative supply demo
410  DISP "CONNECT DM TO NEGATIVE"
420  DISP "FLOATING SUPPLY"
430  DISP
440  DISP "ENTER NEGATIVE VOLTAGE"
450  DISP "(0 TO -32 VOLTS)"
460  INPUT N
465  ! check for input within tolerance
470  IF ABS(N)>=0 AND ABS(N)<=32 THEN 510
480  DISP "YOU HAVE MADE AN ERROR"
490  DISP "TRY AGAIN"
500  GOTO 430
505  ! set negative supply voltage
510  OUTPUT 722;"VNEG",N
```

```
515  ! turn on PS output
520  OUTPUT 722;"OUT ON"
525  ! delay for meter
530  WAIT 1000
535  ! read DM
540  OUTPUT 716;"SEND"
550  ENTER 716;N$
560  PRINT "NEGATIVE VOLTAGE IS:",N$
570  PRINT
580  DISP "TRY ANOTHER VALUE(Y/N)?"
590  INPUT Y$
600  IF Y$="Y" THEN 400
605  ! set PS to power-on state
610  OUTPUT 722;"INIT"
620  CLEAR
630  ! positive supply
640  DISP "CONNECT DM TO POSITIVE"
650  DISP "FLOATING SUPPLY"
660  DISP
670  DISP "ENTER DESIRED VOLTAGE"
680  DISP "(0 TO 32 VOLTS)"
690  DISP
700  INPUT P
705  ! check for input within tolerance
710  IF P>=0 AND P<=32  THEN 750
720  DISP "YOU HAVE MADE AN ERROR"
730  DISP "TRY AGAIN"
740  GOTO 660
745  ! set positive supply voltage
750  OUTPUT 722;"VPOS",P
760  OUTPUT 722;"OUT ON"
765  ! delay for meter
770  WAIT 1000
775  ! read DM
780  OUTPUT 716;"SEND"
```

```
790  ENTER 716;P$
800  PRINT
810  PRINT "POSITIVE VOLTAGE IS:",P$
820  DISP "DO YOU WISH TO CHANGE VPOS"
830  DISP "(Y/N)?"
840  INPUT Y$
850  IF Y$="Y" THEN 660
860  OUTPUT 722;"INIT"
870  CLEAR
880  DISP "GOODBYE"
890  END
```

C. 488XLI AND 22XLA DEMONSTRATION PROGRAM

This program provides a simple demonstration of some of the capabilities of the Photodyne 488XLI and 22XLA combination. An input may be provided to the 22XLA but is not necessary for this demonstration.

```
 10  ! 488XLI and 22XLA Demonstration
 20  ! Non-trigger address is 02
 30  ! Termination sequence is CR-LF
 35  ! Set termination sequence
 40  CONTROL 7,16,; 130,13,10
 50  CLEAR
 60  DISP "488XLI SAMPLE PROGRAM"
 70  ! read data from 22XLA via 488XLI
 80  ENTER 702;A
 90  LET A=A/100
100  ! Display data on CRT
110  DISP USING 120;A
120  IMAGE DDDD.DD,"IEM"
130  GOTO 70
140  END
```

D. PROGRAM TO DEMONSTRATE THE HP-9111A GRAPHICS TABLET.

This program demonstrates some of the uses of the Hewlett-Packard Model 9111A Graphics Tablet when used with the HP-85 Microcomputer. The HP-85 and HP-9111A are the only equipment needed for this program. This program is a modification of a program found in Ref. 9.

```
10  ! program for 9111A Graphics
20  ! Tablet
30  ! Tablet address = 06
35  ! Print softkey menu
40  PRINT "SOFTKEY 1 = COPY CRT TO PRINTER"
50  PRINT "SOFTKEY 2 = ERASE CRT AND CLEAR FILES"
60  PRINT "SOFTKEY 3 = SINGLE-SAMPLE MODE"
70  PRINT "SOFTKEY 4 = SWITCH-FOLLOW,"
80  PRINT "CONTINUOUS-SAMPLE MODE"
90  PRINT "SOFTKEY 5 = SWITCH-NORMAL,"
100 PRINT "CONTINUOUS-SAMPLE MODE"
105 ! set variables and IC's
110 OPTION BASE 0
120 DIM K$[25]
130 K$="BP36,50,3;BP34;BP32;BP30"
140 SHORT X(1000),Y(1000),
150 INTEGER P(1000)
160 X(0),Y(0),P(0),J,F1=0
170 PLOTTER IS 1
175 ! initialize tablet
180 OUTPUT 706;"IN:CN:SF"
185 ! initialize graph
190 GCLEAR
200 GRAPH
210 LIMIT 0,97,0,70
220 FRAME
230 SCALE 0,301,0,218
240 FOR I=1 TO 5
```

```
250  READ V
260  T$[I,I]=CHR$(V)
270  NEXT I
280  DATA 4,4,31,4,4
285  ! check for interrupt
290  ON INTR 7 GOSUB 390
300  OUTPUT 706;"IM,132"
310  ENABLE INTR 7,8
315  ! input tablet coordinates
320  OUTPUT 706;"OC" @ ENTER 706;X,Y
330  X=X/40 @ Y=Y/40
340  IF X<5 OR X>300 THEN 320
350  IF Y<1 OR Y>216 THEN 320
360  MOVE X-5,Y+2 @ BPLOT T$,1 @ MOVE
     X-5,Y+2 @ BPLOT T$,1
370  GOTO 320
380  ! Check status of interrupt
390  STATUS 7,1;A
400  OUTPUT 706;"OS"
410  ENTER 706;S1
420  IF BIT(S1,2) THEN GOSUB 450
430  IF BIT(S1,7) THEN GOSUB 530
440  ENABLE INTR 7,8  @ RETURN
450  IF F1=1 THEN PLOT X(J),Y(J),P(J)
460  J=J+1
470  IF J>1000 THEN 590
480  OUTPUT 706;"OD"
490  ENTER 706;S,T,U
500  X(J)=S/40 @ Y(J)=T/40 @ P(J)=U
510  PLOT X(J),Y(J),P(J)
520  RETURN
530  OUTPUT 706;"RS1"
540  ENTER 706;K
550  OUTPUT 706;K$
560  ! Call subroutine dependant on menu softkey
```

```
570  ON K GOSUB 670,700,750,800,850,730,730,730,
     730,730,730,730,730,730,730,730
580  RETURN
590  GCLEAR
600  FRAME
610  MOVE X(1),Y(1)
620  FOR J=1 TO 1000
630  PLOT X(J),Y(J),P(J)
640  NEXT J
650  END
660  ! Subroutine to copy graph
670  COPY
680  RETURN
690  ! Subroutine to clear graph
700  GCLEAR
710  FRAME
720  J=0
730  RETURN
740  ! Subroutine for single-sample mode
750  OUTPUT 706;"SG"
760  F1=1
770  P(J)=0
780  RETURN
790  ! Subroutine for switch-follow,
     continuous-sample mode
800  OUTPUT 706;"CN;SF"
810  F1=0
820  P(J)=0
830  RETURN
840  ! Subroutine for switch-normal
     continuous-sample mode
850  OUTPUT 706;"CN;SN"
860  F1=0
870  P(J)=0
880  RETURN
```

E. FREQUENCY-VS-GAIN PROGRAM (PRINTED OUTPUT)

This program will test and print out the frequency and gain at that frequency for a circuit connected to the programmable test equipment:

```
10  ! Program for freq-gain
20  ! Test equipment addresses
30  ! Function generator = 20
40  ! Power supply = 22
50  ! Multimeter = 16
60  ! Poll test equipment
70  LOCAL LOCKOUT 7
80  S=SPOLL(722)
90  S=SPOLL(716)
100 ! Initialize test equipment
110 OUTPUT 716;"ACV"
120 OUTPUT 722;"INIT"
130 !Set power supply
140 CLEAR
150 DISP "ENTER NEGATIVE VOLTAGE"
160 DISP "(0 TO -32 VOLTS)"
170 INPUT N
175 ! check input within tolerance
180 IF ABS(N)<=32 THEN 220
190 DISP "YOU HAVE MADE AN"
200 DISP "INCORRECT ENTRY"
210 GOTO 150
220 OUTPUT 722;"VNEG",N
230 DISP "ENTER POSITIVE VOLTAGE"
235 DISP "(0 TO 32 VOLTS)"
240 INPUT P
245 ! input within tolerance?
250 IF P>=0 AND P<=32 THEN 290
260 DISP "YOU HAVE MADE AN"
270 DISP "INCORRECT ENTRY"
```

```
280  GOTO 230
290  OUTPUT 722;"VPOS",P
300  ! Enter other parameters
310  DISP "ENTER STARTING FREQUENCY"
320  INPUT F1
330  DISP "ENTER ENDING FREQUENCY"
340  INPUT F2
345  ! check frequencies
350  IF F1<F2 THEN 400
360  DISP "ENDING FREQUENCY IS"
370  DISP "LESS THEN STARTING"
380  DISP "FREQUENCY"
390  GOTO 310
400  DISP "ENTER NUMBER OF POINTS"
410  DISP "(100 POINTS IS USUALLY ENOUGH)"
420  INPUT N1
430  ! Display parameters
440  CLEAR
450  DISP "NEGATIVE VOLTAGE =",N
460  DISP "POSITIVE VOLTAGE =",P
470  DISP "STARTING FREQ =",F1
480  DISP "ENDING FREQ =",F2
490  DISP "# OF POINTS =",N1
500  DISP
510  DISP "DO YOU WISH TO CHANGE"
520  DISP "(Y/N)?"
530  INPUT Y$
540  IF Y$="Y" THEN 140
550  ! Turn on power supply
560  OUTPUT 722;"OUT ON"
570  ! Set up function generator
580  OUTPUT 720;"C0A1B0F",F1,"P1I"
590  ! Start taking data
600  PRINT
610  PRINT "FREQUENCY-vs-GAIN"
```

```
620  PRINT "FREQ:        GAIN:"
630  F2=F1
640  B=(F2-F1)/(N1-1)
650  FOR I=1 TO N1
660  WAIT 1000
665  ! read meter
670  OUTPUT 716;"SENT"
680  ENTER 716;P1
685  ! compute gain
690  G=20*LOG(P1*P1 /.5)
695  ! print frequency and gain
700  PRINT USING 710;F2,G
710  IMAGE DDDDDDD.D,"Hz",DDDD.DD,"dB"
720  F2=INT(B)*I+F1
725  ! set 270 to next frequency
730  OUTPUT 720;"F",F2,"I"
740  NEXT I
750  DISP "DO YOU WISH ANOTHER RUN"
760  DISP "(Y/N)?"
770  INPUT Y$
780  IF Y$="Y" THEN 100
790  DISP "GOODBYE"
800  END
```

F. FREQUENCY-VS-GAIN PROGRAM (GRAPH OUTPUT)

This program is a modification of the frequency-vs-gain program of Section E using the HP-85 graphics capabilities. The data points are graphed on the computer display and then the display is copied on the printer.

```
10   ! Program for freq-gain (graphic)
20   ! Test equipment addresses
30   ! Function Generator = 20
40   ! Power Supply = 22
50   ! Multimeter = 16
60   ! Poll test equipment
70   LOCAL LOCKOUT 7
75   ! initialize variables
80   DIM P1(2,150)
90   S=SPOLL (722)
100  S=SPOLL(716)
110  ! Initialize test equipment
120  OUTPUT 716;"ACV"
130  OUTPUT 722;"INIT"
140  ! Set Power Supply
150  CLEAR
160  DISP "ENTER NEGATIVE VOLTAGE"
170  DISP "(0 TO -32 VOLTS)"
180  INPUT N
185  ! input within tolerance?
190  IF ABS(N)<=32 THEN 230
200  DISP "YOU HAVE MADE AN"
210  DISP "INCORRECT ENTRY"
220  GOTO 160
230  OUTPUT 722;"VNEG",N
240  DISP "ENTER POSITIVE VOLTAGE"
250  INPUT P
255  ! Check if input within tolerance
260  IF P>=0 AND P<=32 THEN 300
```

```
270  DISP "YOU HAVE MADE AN"
280  DISP "INCORRECT ENTRY"
290  GOTO 240
300  OUTPUT 722;"VPOS",P
310  ! Enter other parameters
320  DISP "ENTER STARTING FREQUENCY"
330  INPUT F1
340  DISP "ENTER ENDING FREQUENCY"
350  INPUT F2
355  ! check frequency order
360  IF F1<F2 THEN 410
370  DISP "ENDING FREQUENCY IS"
380  DISP "LESS THEN STARTING"
390  DISP "FREQUENCY"
400  GOTO 320
410  DISP "ENTER NUMBER OF POINTS"
420  DISP "(150 POINTS MAX)"
430  DISP "(100 POINTS IS USUALLY PLENTY)"
440  INPUT N1
450  ! Display parameters
460  CLEAR
470  DISP "NEGATIVE VOLTAGE =",N
480  DISP "POSITIVE VOLTAGE =",P
490  DISP "STARTING FREQ =",F1
500  DISP "ENDING FREQ =",F2
510  DISP "# OF POINTS ="N1
520  DISP
530  DISP "DO YOU WISH TO CHANGE"
540  DISP "(Y/N)?"
550  INPUT Y$
560  IF Y$="Y" THEN 150
570  ! Turn on power supply
580  OUTPUT 722;"OUT ON"
590  ! Set up function generator
600  OUTPUT 720;"COA1EOF",F1,"P1I"
```

```
610  ! Start taking data
620  PRINT
630  PRINT "FREQUENCY-vs-GAIN"
640  PRINT "FREQ:        GAIN:"
650  P1(1,1)=F1
660  B=(F2-F1)
670  FOR I=1 TO N1
675  ! delay for meter
680  WAIT 1000
690  OUTPUT 716;"SEND"
700  ENTER 716;G
705  ! compute gain
710  P1(2,I)=20*LOG(G*G/.5)
715  ! print frequency and gain
720  PRINT USING 730;P1(1,I),P1(2,I)
730  IMAGE DDDDDDD.D,"Hz",DDDD.DD,"dB"
740  P1(1,I+1)=INT(B/(N1-1))*I+F1
745  ! set 270 to next frequency
750  OUTPUT 720;"F",P1(1,I+1),"I"
760  NEXT I
770  ! initialize plot
780  GCLEAR
790  SCALE F1-2*B,F2,-20,110
800  XAXIS 0,.1*B
810  YAXIS 0,10
815  ! plot points stored
817  ! in array p1
820  FOR I=1 TO N1
830  PLOT P1(1,I),P1(2,I)
840  NEXT I
850  PENUP
855  ! label plot
860  LDIR 0
870  MOVE .3*B,80
880  LABEL "MAG(dB) vs FREQ"
```

```
890  MOVE .1*B,-10
900  LABEL "FREQ(",.1*B,"Hz STEPS"
910  LDIR 90
920  MOVE F1-.1*B,20
930  LABEL "MAG(10dB STEPS)"
935  ! copy plot on printer
940  COPY
950  DISP "DO YOU WISH ANOTHER RUN"
960  DISP "(Y/N)?"
970  INPUT Y$
980  IF Y$="Y" THEN 110
990  DISP "GOODBYE"
1000 END
```

G. FREQUENCY-VS-GAIN PROGRAM (DISK OUTPUT)

This program is a modification of an earlier frequency-vs-gain program. This program writes a file onto a disk which is compatible with the VZWRITE subprogram of VisiCalc Plus. Output is stored by rows, frequency and then gain. The data disk is assumed to be "INITIALIZED" and the micro-computer must be using that disk as its mass storage device.

```
 10  ! Program for Freq-Gain (disk)
 20  ! Test equipment addresses
 30  ! Function Generator = 20
 40  ! Power Supply = 22
 50  ! Multimeter = 16
 60  ! Poll test equipment
 70  LOCAL LOCKOUT 7
 80  S=SPOLL(722)
 90  S=SPOLL(716)
100  ! Initialize test equipment
110  OUTPUT 716;"ACV"
120  OUTPUT 722;"INIT"
130  ! Set Power Supply
140  CLEAR
150  DISP "ENTER NEGATIVE VOLTAGE"
160  DISP "(0 TO -32 VOLTS)"
170  INPUT N
175  ! input within tolerance?
180  IF ABS(N)<=32 THEN 220
190  DISP "YOU HAVE MADE AN"
200  DISP "INCORRECT ENTRY"
210  GOTO 150
215  ! set negative supply
220  OUTPUT 722;"VNEG",N
230  DISP "ENTER POSITIVE VOLTAGE"
235  DISP "(0 TO 32 VOLTS)"
240  INPUT P
```

```
245  ! input within tolerance?
250  IF P>=0 AND P<=32 THEN 290
260  DISP "YOU HAVE MADE AN"
270  DISP "INCORRECT ENTRY"
280  GOTO 230
285  ! set positive supply
290  OUTPUT 722;"VPOS",P
300  ! Enter other parameters
310  DISP "ENTER STARTING FREQUENCY"
320  INPUT F1
330  DISP "ENTER ENDING FREQUENCY"
340  INPUT F2
345  ! frequencies in order?
350  IF F1<F2 THEN 400
360  DISP "ENDING FREQUENCY IS"
370  DISP "LESS THEN STARTING"
380  DISP "FREQUENCY"
390  GOTO 310
400  DISP "ENTER NUMBER OF POINTS"
405  DISP "(MAX 150)
410  DISP "(100 POINTS IS USUALLY PLENTY)
420  INPUT N1
430  ! Input disk filename
440  DISP "ENTER FILENAME FOR DISK"
450  INPUT A$
460  ! Display parameters
470  CLEAR
480  DISP "NEGATIVE VOLTAGE =",N
490  DISP "POSITIVE VOLTAGE =",P
500  DISP "STARTING FREQ =",F1
510  DISP "ENDING FREQ =",F2
520  DISP "# OF POINTS =",N1
530  DISP "FILENAME =",A$
540  DISP
550  DISP "DO YOU WISH TO CHANGE"
```

```
560  DISP "(Y/N)?"
570  INPUT Y$
580  IF Y$="Y" THEN 140
590  ! Turn on power supply
600  OUTPUT 722;"OUT ON"
610  ! Set up function generator
620  OUTPUT 720;"C0A1B0F",F1,"P1I"
630  ! Set up disk
640  CREATE A$,300,10
650  ASSIGN# 1 TO A$
660  ! Start taking data
670  PRINT
680  PRINT "FREQUENCY-vs-GAIN"
690  PRINT "FREQ          GAIN"
700  F2=F1
710  B=(F2-F1)/(N1-1)
720  FOR I=1 TO N1
725  ! delay for meter
730  WAIT 1000
735  ! read meter
740  OUTPUT 716;"SENI"
750  ENTER 716;P1
755  ! compute gain
760  G=20*LOG(P1*P1/.5)
770  PRINT USING 810;F2,G
780  ! Write to disk
790  PRINT# 1,2*I-1;F2
800  PRINT# 1,2*I;G
810  IMAGE DDDDDDD.D,"Hz",DDDD.DD,"dB"
820  F2=INT(B)*I+F1
825  ! set 270 to next frequency
830  OUTPUT 720;"F",F2,"I"
840  NEXT I
850  ! Close disk file
860  ASSIGN# 1 TO *
```

```
870  DISP "DO YOU WISH ANOTHER RUN"
880  DISP "(Y/N)?"
890  INPUT Y$
900  IF Y$="Y" THEN 100
910  DISP "GOODBYE"
920  END
```

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